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REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

OF MICHIGAN

FOR THE YEAR 1904

BY AUTHORITY

1905
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[1] With the permission of the Director U. S. Geological Survey.

ERRATA

Page 159, line 18 from top for westward read eastward.

Plate II was omitted as unnecessary, although it is mentioned in the table of contents on p 36.

FAILURE OF WELLS

ALONG THE LOWER HURON RIVER, MICHIGAN

IN 1904

BY

MYRON L. FULLER

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICHIGAN, Feb. 8, 1905.

To the Honorable the Board of Geological Survey of the State of Michigan:

HON. FRED M. WARNER, President.
HON. L. L. WRIGHT.
HON. PATRICK H. KELLEY, Secretary.

Gentlemen:—I herewith transmit, with the request that it be published as part of the annual report of the Board for 1904, a paper by Myron L. Fuller of the U. S. Geological Survey on "Failure of Wells Along the Lower Huron River, Michigan, in 1904." Mr. Fuller is connected with the U. S. Geologica Survey and was formerly an employe of this Survey. He is now in charge of the hydrology of the eastern United States. He kindly consented to examine this problem which has occasioned local embarrassment and newspaper comment, and the report is published with the permission of the Director of the U. S. Geological Survey. I asked the especially prompt publication of this report because it has a bearing on proposed legislation.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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FAILURE OF WELLS ALONG THE LOWER HURON RIVER, MICHIGAN, IN 1904*

BY MYRON L. FULLER.

INTRODUCTION.

General statement.—In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of the Huron river in southeastern Michigan, which up to that time had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes. Wide attention was attracted to the failure of the wells in the region because the shortage was supposed to have been brought about through under-drainage by a powerful flowing well on Grosse Isle a few miles to the east. Careful field investigations showed the improbability of such influence, the evidence indicating on the contrary the failure to be due to certain general causes of rather widespread application.

The explanation of the failure of wells in the region in question is similar to that in like districts at many points throughout the country, and it is with the object of calling attention to certain general factors, both temporary and permanent, which tend to induce a shortage of the ground water supplies over large areas that the present paper has been prepared.

Field work and acknowledgments.—The first study of the conditions of the district as made in July, 1904, by Mr. Frank Leverett, geologist, at the suggestion of the State geologist, who made a reconnaissance in the vicinity of Carleton, Flat Rock, Willow and Waltz, determining the general conditions as regards shortage. In August, the shortage still continuing, the writer visited the field and made a more detailed study of the conditions of the wells and of the cause of their failure, the results of which are presented herewith. Acknowledgments for certain geologic and well data are made to Mr. Frank Leverett, and Messrs. A. C. Lane and W. H. Sherzer of the State Geological Survey. Thanks are also due to Mr. James Swan, owner of the Grosse Isle well, and to Mr. Edward Ready and Jacob J. Lucke of Carleton for courtesies rendered.

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WATER SUPPLIES OF THE LOWER HURON RIVER REGION.

GENERAL CONDITIONS.

Location of area.—The region in which the shortage of water in 1904 was earliest felt, and in which it was severest, is a belt perhaps 10 miles wide extending in a northwest-southeast direction parallel with and including the Huron river from a point near New Boston, about 20 miles in a straight line above its mouth, to its juncture with the Detroit river, 28 miles from Detroit city. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. To the south the affected area is not only much broader, reaching a width of 7 or 8 miles, but the shortage was more pronounced, reaching a maximum along Swan Creek which parallels Huron river at a distance of from 3 to 5 miles on the south. South of Swan Creek the wells are affected only for a short distance, usually not over 2 or 3 miles.

The belt showing shortage lies in two counties, the relatively narrow strip north of the Huron river being in Wayne county and the wider one south of the river in Monroe county. The villages principally affected are Willow, Waltz, Carleton, Flat Rock and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

Character of country.—The entire region is characteristically flat, and, except in the vicinity of the streams which have cut shallow channels for themselves, almost no inequalities recognizable by the eye are to be seen over large areas. The surface materials are generally clayey, although locally the clay may be overlain by thin sheets of sand, which in places take the shape of low flat northeast-southwest ridges or terraces, representing old beach lines of the lake which formerly covered the region. Although excessively flat the country has a gentle slope southeastward towards Lake Erie, usually not exceeding 5 feet to the mile. The main streams, the Huron river and Swan Creek, flow in the direction of greatest slope to the southeast, while the smaller streams, including the tributaries of the larger streams named, flow either along similar southeast lines or converge slightly towards the main drainage lines.

The region is a populous one. Roads follow nearly every section line and houses are abundant, there being frequently from 10 to 20 to a section. The farms are correspondingly small, but are under careful cultivation and the owners appear to be prosperous. Three steam railroads and a trolley line give frequent communication with Detroit and afford abundant opportunity for the shipping of produce.

Climate.—The climate of the region is tempered to a certain extent by the proximity to Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39 degrees, the average maximum 57degrees, and the average mean 48 degrees. The rainfall, which is about 30 inches, is low as compared with certain other portions of the state where it may reach to from 35 and 40 inches. (See fig. 1.)

There are, however, considerable areas in which the precipitation does not exceed 30 inches. Normally the rainfall is lowest in January, when it is under 2 inches, and highest in May and June, when it is over 3½ inches per month. About the head of Huron river the rainfall is greater than along the lower part of its course and serves to keep the stream somewhat higher than would otherwise be the case.

GEOLOGY.—SURFACE MATERIALS.

Character.—The materials overlying the rock in the region consist largely of what is locally called clay, but which is more properly a clay with an admixture of sand and pebbles. The materials are not usually arranged in definite layers as in stratified deposits, but commonly exist rather as heterogeneous mixtures, although occasional beds of quicksand or gravel, or even scattered bowlders may occur. In consistency the material is tough and clay-like, and is of a grayish blue color when fresh, but becoming yellowish through oxydation of the iron on exposure to the weather at the surface. Some bowlders occur in the part of the area nearest the Detroit river.

Thickness.—Although the superficial materials have a flat surface, their thickness varies from place to place because of differences in elevation of the buried rock surface which reaches much nearer to the top of the ground in some places than in others. The clayey deposits are from 15 to 40 feet in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and may even have cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface as at the large quarries at Newport.

In a broad way the thickness of the clays may be said to increase as Detroit river and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 35 feet, while near Rockwood the thickness may be as high as 40 feet.

Origin.—The surficial materials are of somewhat diverse origin. The bowlders and the unstratified materials were derived from the glacial ice which once covered the region, the accumulation taking place under the ice, or very close to its margin during halts in its retreat. The waters at that time stood higher than at present, covering the entire area under discussion, reaching back as far as the base of the hills near Ypsilanti, and in them a portion of the clays and the sand locally covering the surface were deposited as the ice retreated. Ice and water deposition were simultaneous and without sharp lines of demarcation, making it difficult to differentiate one from the other. After the retreat of the ice from the region the waters finally sank, with several halts at different levels, to their present position. During these halts the deposits were subjected to more or less washing by the waves, with the result that beaches were cut in the clay or constructed of sandy materials derived from it. These are the so-called terraces, ridges or beaches extending in a northeast-southwest direction across the region northwest of the area under discussion and between it and Ypsilanti.

ROCKS.

Character of rock surface.—As was pointed out in the paragraph in which the thickness of the surface deposits was discussed, the rock surface is irregular as compared with that of the overlying clays, rising at points until it is within a few feet of the surface and again sinking 20, 30 or 40 feet below it.

Fig. 1. Rainfall map of Michigan.

Fig. 2. Sketch map of the lower Huron region and vicinity.

There are no great inequalities, however, and even if the soil were removed the surface would still be very regular, with elevations rarely rising more than 20 feet above the surrounding level. The irregularities are entirely independent of the present streams, which in the main have been determined in location entirely by the surface deposits.

Nature of rocks.—The rocks underlying the clays in the lower Huron river region consist of limestones, sandstones, shales, etc., arranged in belts extending in a northeast-southwest direction, or at right angles to the course of the Huron river. They are reached by all but the shallow dug wells, and afford the greater part of the ground water found in the region.

Dundee limestone.—In the northwestern portion of the area, or beyond a point a couple of miles northwest of Carleton, the rock is the Dundee limestone, a fairly pure, light colored, flint bearing Devonian limestone of perhaps 100 feet in thickness and dipping northwestward at a rate of 20 to 25 feet to a mile. It is characterized by waters more or less charged with sulphur in the form of hydrogen sulphide.

Upper Monroe beds.—These are drab magnesian limestones or dolomites, sometimes carrying sand, and gypsum and other minerals. The dip is similar to that of the Dundee limestone. The waters are hard, but are not characterized by much sulphur.

Sylvania sandstone.—This is a white sandstone outcropping beneath the clay in the region at a point about a mile east of Carleton nearly to the mouth of the Huron river. The dip is somewhat flatter than either of the preceding and is more to the north than to the northwest. It yields water of a good quality.

Lower Monroe beds.—These are generally similar to the limestones and dolomites constituting the upper part of the Monroe beds already described, but are often more silicious than the latter. They outcrop parallel to the Sylvania sandstone in a narrow belt along Lake Erie and Detroit river. Their waters carry some sulphur.

WATER SUPPLIES.

The conditions as regards water supplies vary considerably throughout the region under consideration, the variations being marked by differences in composition, head, volume, and in the amount of shortage shown in the time of drought. Each of the individual areas will be separately considered.

WILLOW-EXETER REGION.

General conditions.—The term Willow-Exeter region is applied to the area, now or formerly furnishing flowing wells, which extends from the vicinity of Willow southwestward past Waltz into Exeter township, Monroe county, at its northeast corner. The area in this township is mainly included in sections 1, 11, 12, 13 and 14, with parts in sections 2, 10 and 15. The belt lies transverse to the drainage of the region and is located mainly over the outcrop of the Dundee limestone.

Character of wells and water.—There are several types of wells in the district, including dug wells obtaining a very limited supply of non-sulphur water from the clays, the drilled wells passing through the clay and penetrating the rock obtaining strong sulphur waters which will frequently flow at the surface, and a combination of the dug and drilled types uniting the characters of both of the preceding types. Such wells are usually dug about 15 feet, a small drilled hole being continued from the bottom down to the rock, which is usually penetrated for a foot or two. Such wells are particu-

larly adapted to those cases where the water will rise nearly, but not quite, to the surface. They furnish, under such conditions, admirable opportunities for storage and will ordinarily yield much more water than the simple pipe wells, which often show a strong tendency to become clogged when water is most needed.

The depth of the wells varies from about 15 to 35 feet, of which all but a foot or two is usually through the clay. The depth is least at the eastern limits and greatest at the western border of the district. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams, or in sags of the surface, that good flows are obtained.

Condition of wells in 1904.—The portion of the district near Willow was visited on July 18, 1904, by Mr. Frank Leverett, who furnishes the data in the following paragraph:

Extending a mile or more both to the east and west of Willow is a line of flowing wells averaging 60 feet in depth and obtaining sulphur water. They all draw from the same horizon and have always interfered more or less with one another. The flowing well of Henry Ludwig, on the west side of the N. W. ¼ of section 28, which penetrated 50 feet of clay, etc., with a crust at its base before entering the rock, had a marked effect on the other wells, reducing the head or even, in cases, stopping the flow altogether. The flow of the Ludwig well was as strong as usual in July, however.

The data for the other portions of the district was collected by the writer and are presented in the accompanying table.

CONDITION OF WELLS IN WILLOW-EXETER REGION IN AUGUST, 1904.

Owner	Location.				Depth.	Head		Shortage noted.	Remarks.
	T	R	S	Q		Max.	Pres.		
R. Woodward	5	9	17	sw	16	.....	−8	.....	Type of well in clay. No shortage.
J. J. Lucke	5	9	18	se	45	−20	−20	.....	Type of sandstone well. Good water. No shortage.
J. S. Ankerbrandt	5	9	20	nw	21	−10	−17	June	Tiled well. Roily before storm.
Frank Woodward	5	9	20	e	.....	.....	.....	.....	Two wells, type unknown, both dry.
George Burgess	5	9	19	ne	18	−6	−10	not n't'd	Sandstone well. Plenty water left.
Frank Dusheck	5	9	18	sw	33	+0	−12	.....	Plenty of water by pumping.
John Wenzel	5	8	13	se	41	−6	−6	.....	No shortage. Sandstone water.
Jas. Dunn	5	8	13	ne	.....	−1	−3	July	Plenty sulphur water. A surface well goes dry every season.
J. Crimins	5	8	13	sw	.....	−3	−3	.....	Sulphur water. Went dry in spring but water returned on cleaning well.
Henry Kingsley	5	8	13	nw	28	+0	−2	July	Sulphur water. Ahother well still flows.
Edw Navarre	5	8	13	e	.....	.....	.....	.....	Lowered but still plenty.
Frank Ochs	5	8	14	ne	28	±0	±0	1902	Plenty sulphur water but less than before 1902. No recent shortage.
John Theisen	5	9	24	...	.....	.....	.....	.....	Good flow just struck.
D. Livernois	5	8	14	e	20	.....	.....	.....	No sulphur. Plenty.
F. Maynes	5	8	14	e	30	+3	+½	.....	Sulphur water. No recent decline.
Phillip Zink	5	8	14	e	30	−4	−4	.....	Sulphur water. As much as usual.
F. Maynes (field)	5	8	14	nw	33	.....	+0	.....	New sulphur well.
J. W. Zink	5	8	10	se	37	−3	−8	.....	Always improved by cleaning.
John Murphy	5	8	11	sw	35	+0	−8	.....	Sulphur. Failed once before but flowed again on cleaning.
C. S. Davis	5	8	2	sw	.....	.....	.....	.....	Fresh and sulphur wells. No unusual shortage.
A. W. Dexter	5	8	11	nw	.....	.....	.....	.....	Fresh and sulphur wells. No unusual shortage.
A. Fay	5	8	2	s	.....	.....	.....	.....	Fresh and sulphur wells. No unusual shortage.
M. Vasher	5	8	1	se	32	+4	+3	.....	Sulphur water. Weakened but supply returned on cleaning.
F. Livernois	5	8	1	sw	.....	.....	.....	.....	Stopped at first and permanently weakened by Vasher well. Well of Dan. Fay also weakened.
Wm. Gauss	5	8	12	sw	40	−9	−9	.....	No change. Sulphur water.
Sam Gauss	5	8	12	sw	44	−3	−3	.....	No change. Sulphur water. Surface wells dry.
Jos. Discher	5	9	7	sw	.....	−8	−8	.....	No shortage. Surface wells full.
C. Heinzerling	5	9	18	nw	28	−14	−16	.....	No unusual shortage. Sulphur water.
J. J. Lucke	5	9	7	se	22	−3	−18	1903	Sulphur well improved by cleaning Surface wells all right.
J. H. Jewell	5	9	7	ne	.....	+0	−3	spring	Flowed up to May. Sulphur water.

Summary.—An examination of the above table will show the conditions are not uniform. As to the surface wells, several are reported dry, while others report the supply to be the same as usual. No decrease is noted in the wells in the sandstone, and most of the limestone wells (yielding sulphur water) show little if any material shortage, although a few report losses which, in several instances, were returned wholly or in part after cleaning. Some interference exists.

No evidence is afforded by the wells to show that there is any shortage, except such as would always accompany an unusually dry season. The moderate decrease due to drought has not been uniform, but was felt first by the shallower wells, or by those yielding small supplies, and last by the deeper and stronger wells. The difference is naturally generally most noticeable in the flowing wells, in which a difference of a foot or two in head may determine whether it will flow or not. Shortage in previous years is reported.

The head of the water in relation to altitude declines from 622 feet above sea level in the western part of section 14, T. 5, R. 8, to 600 feet near the east line of section 19 of the next township east, or a little over 7 feet to the mile. It would indicate that the source of the supply was to the west, probably in the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of non-flowing wells, lying between the Willow-Exeter and the Swan Creek flowing well districts. The wells are commonly about 30-35 feet deep and probably enter the Sylvania sandstone for a few feet from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August although the wells were somewhat lower than usual.

SWAN CREEK REGION.

General conditions.—This is a region of flowing wells extending along the valley of Swan Creek from near the Detroit Southern railroad 1½ miles northeast of Carleton southeast to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron river and Rockwood districts of flowing wells. The area is mainly over the outcrop of the Sylvania sandstone.

Character of wells and water.—The wells are of the dug, drilled, or dug and drilled types. Except those of the first type, they all obtain their water on entering the rock after passing through the stiff impervious clays. The wells have hitherto always yielded good flows of non-sulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

Conditions of wells in 1904.—The data relating to the condition of the wells is most conveniently presented in the form of the table which is given below. Besides the wells of the district proper, or the flowing well area, a number located within a mile or so outside the limits are included.

CONDITION OF WELLS IN SWAN CREEK REGION IN AUGUST, 1904.

Owner	Location				Depth	Head.		Shortage noted	Remarks
	T	R	S	Q		Max.	Pres.		
John Cequin	5	9	17	se	33	.....	.....	.....	No decrease. Suggests ditching as cause of shortage in other wells.
Henry Spicer	5	9	20	ne	35	.....	.....	.....	No decrease.
Albert Spicer	5	9	21	sw	30	.....	.....	.....	No decrease in rock well, surface well failed.
Wm. Sillmore	5	9	20	se	30	.....	.....	June	Just to rock (surface well). Failed.
L. Graves	5	9	20	se	37	.....	.....	March	Low, cleaned without result.
J Lantenschlager	5	9	21	sw	32	.....	.....	.....	18 feet, dug. Water only in pipe.
Sam McLaughlin	5	9	28	ne	.....	.....	.....	June	To rock only Three wells went dry. Little better after cleaning.
Benj. McLaughlin	5	9	28	ne	26	±0	−0	spring	Flowed 30 years ago. Dug 8 feet. Water in pipe only
Frank Bergmoser	5	9	22	sw	22	+0	−0	May	Nearly dry. Always plenty before.
Frank Bergmoser	5	9	22	sw	28	.....	.....	April	Dry. Has failed before.
Frank Bergmoser	5	9	22	sw	27	.....	.....	May	Dug 13 feet. Water in pipe only.
Henry Hood	5	9	21	se	28	−10	−16	Aug	Deepened with success. Another lower well stopped flowing.
Mrs P. Kelly	5	9	28	se	.....	.....	.....	.....	Nearly enough.
Ed. McCormick	5	9	28	se	30	−5	−11	June	Assigns loss to frozen ground and Newport quarry. Well improved by cleaning.
B. McLaughlin	5	9	28	se	.....	.....	.....	.....	No trouble with wells.
Jos. Esper	5	9	32	ne	20	−3	−15	June	Surface well. Ascribes loss to frozen ground.
J. Funerstalk	5	9	27	s	35	−10	.....	spring	Dug 12 feet. Water in boring only.
La Ranger	5	9	35	nw	.....	−4	−4	.....	No change. Large supply
C. Muth	5	9	33	nw	21	−6	−10	.....	Low but still plenty of water.
Geo. Calkins	5	9	35	ne	21	−5	−10	.....	Enters slowly but plenty of water. Ascribes shortage to frost.
Nicholas Noel	5	9	25	sw	14	−12	−13	.....	Surface well. A little less than usual. Two other similar wells in vicinity get plenty of water.
E. H. Van Tassel	5	9	25	se	.....	.....	.....	.....	To rock, no decrease noted.
W. M. Swype	5	9	25	sw	20	−10	−19	July	At barn. Never dry before Drilled wells at house as much as usual.
Wm. Southworth	5	9	25	nw	33	−6	−6	.....	No trouble. One well used to flow.
S. Uden	5	9	.....	.....	.....	.....	.....	.....	On line between secs 24 and 25 Two wells out of three failed.
Peter Bitting	5	9	26	ne	27	−8	−10	.....	Plenty. Another well the same.
B. Parish	5	9	23	s	27	+4	+4	June	In field. Has been low in August of other years.
B. Parish	5	9	23	s	30	−4	−8	June	At house. Has been low in August of other years.
Ed. Parish	5	9	23	s	22	+2	−15	July	Failed suddenly. Three similar wells.
School house	5	9	23	sw	25	+0	−0	May	Run during summer of 1903.
J. McCollum	5	9	23	sw	29	−8	−13	June	Still getting some.
J. McCollum	5	9	23	sw	15	+0	+0	.....	New well near creek.
G. A. Harjst	5	9	22	ne	29	−4	−14	Aug	Very low. Ascribes loss to Grosse Isle well.
Earl Baker	5	9	22	ne	28	−5	.....	.....	Water in pipe only.
Tony Kohn	5	9	?	?	.....	.....	.....	.....	Still gets some water.
Chas. Kriezer	5	9	?	?	.....	.....	.....	.....	Still gets some water.
J. Hedges	5	9	22	se	.....	+0	−0	June	Still gets some water.
A. Benedict	5	9	22	se	.....	+0	−0	.....	Lowered pipe. Water now stands just at top.
Eli Barrow	5	9	15	e	.....	+0	−0	.....	Near creek. Well at house also failed
Edw. Whipple	5	9	14	w	.....	+0	−18	June	Plenty by pumping Ascribes loss to Grosse Isle well.
Mark Baker	5	9	15	e	.....	+0	+0	.....	Slight decrease Ascribes loss to Grosse Isle well.
G. Schweitzer	5	9	15	ne	18	−0	−3	.....	Near creek. Well at house also lowered but improved by going deeper.
F. Baker	5	9	14	sw	.....	+0	−0	1902	Less than usual but plenty
D. Reed	5	9	23	n	.....	.....	.....	.....	Dry but got plenty by going 2 feet deeper.
H. Gretzler	5	9	23	n	32	−5	−11	July	Another well at house failed. Plenty on cleaning.
Barnard Parish	5	9	23	ne	33	−7	−12	May	Supply sufficient. Similar well across road.
C. M. Hood	5	9	13	sw	35	−6	−12	.....	More water by deepening. Another well dry
F. Reinhart	5	9	13	nw	35	.....	−12	.....	New well. Old well failed. Ascribes loss to Grosse Isle well.
A Vizard	5	9	13	nw	35	−6	−11	.....	Another similar well. Supply sufficient. A dug well also has water.
J. F. Smith	5	9	12	sw	.....	.....	.....	.....	Enough for cattle.
Henry Green	5	9	11	se	30	−4	.....	June	Dug 8 feet. Water in pipe only. Very low.
Irwin Barnum	5	9	11	se	28	−5	.....	May	Dug 8 feet. Water in pipe only. Very low.
W. Baker	5	9	14	ne	.....	−8	.....	.....	Surface well. Water by going 7 feet deeper.
Emily Clark	5	9	14	nw	30	−8	.....	spring	Scanty supply.
Fred Renton	5	9	11	sw	37	−5	−13	June	Got more water by going 8 feet deeper.
C. Stumpmoyer	5	9	11	sw	.....	−6	−13	May	Three wells 32, 33 and 35 feet deep. Nearly dry. Cleaned without success. No previous trouble.
G. W. Reeves	5	9	10	se	.....	+0	−0	1902	Another well just to rock has plenty for ordinary use.
M. Reeves	5	9	10	sw	.....	.....	.....	.....	Near creek. Failed. Always plenty before.
J. E. Brown	5	9	10	sw	22	+0	−0	1902	Failed temporarily in August, 1903. and again in spring of 1904
Floyd Barnum	5	9	16	....	.....	−5	- 15	.....	Cleaned with little effect.
Alex Todd	5	9	9	....	20	+0	−0	spring	Plenty of water by pump.

Nature of shortage.—As in the Willow-Exeter region the behavior of the wells is not uniform. In the Swan Creek region, however, nearly every well shows shortage, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very uniformly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while others, though still running, rise to only a part of their former height. In the non-flowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued in some of the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly again in the spring of 1904. Just what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Supposed causes of shortage.—Nothing could be more variable than the opinions presented as to the cause of shortage. The most general of the explanations attributed the loss of water to subterranean drainage by a deep rock well located at the southern extremity of Grosse Isle and flowing at the rate of a barrel a second. Credit was given to this supposed cause by many who would not otherwise have thought of it because of the fact that one or two of the wells near Rockwood ceased to flow temporarily in the fall of 1903, only to begin again a short time after and to continue until the spring of 1904, when they again ceased. These changes are said to have coincided respectively with the striking of the water vein, insertion of casing, and finally with the withdrawing of the pipe from the Grosse Isle well.

Others, however, see no connection with the Grosse Isle well, attributing the shortage to lack of rainfall, the frozen condition of the ground when the rains of the previous autumn fell, the extensive ditching of the land in recent years and the consequent increase of runoff as compared with absorption, and to drainage by the quarry at Newport. All are possible causes and were investigated with the view of finding the determining factor in the shortage.

Steps taken to increase supplies.—Several methods of remedying the shortage were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep-seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening of the well was resorted to. In some cases the dug part was carried a few feet deeper, and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective results were obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although of course it had to be pumped to the surface.

HURON RIVER REGION.

General conditions.—This district extends along the Huron river from a point a mile or two southeast of New Boston, down stream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The

rock is largely Sylvania sandstone, except at the northern end of the district. The wells, as in the previous districts, are of the dug, drilled, or dug and drilled types, and range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water which is non-sulphur-bearing.

Condition of wells in 1904.—No special investigation was made in the New Boston part of the area this season, but the conditions are reported to be similar to those in the Willow-Exeter field, there being relatively little shortage. Some of the wells have, however, stopped flowing, but this is not characteristic of the present season alone. The well of Gus Miesner in S. W. ¼ of section 9 formerly yielded a flow from a depth of between 60 and 70 feet, but it has now ceased flowing. Near the school house, on the west side of section 15, a well, opened by Mr. Blum, flowed a 4 inch stream of sulphur water when first sunk in 1887, but now flows less than one gallon a minute. The well is 65 feet deep. South of the school house Julius Kahm sank a well in 1891 to a depth of 65 feet. This flowed at the start, but soon after ceased.[1]

In the region between the bridge, 2 miles east of Willow, and Flat Rock, most of the wells are still flowing, although some have ceased. North of the river the Horace Thompson well in the southeast part of Huron township is still flowing sulphur water after a lapse of thirty years, though at a level 1½ feet lower than usual. The depth of the well is 26 feet. In section 26 Mrs. Lawrence has a very weak flowing well of black sulphur water. In the N. W. ¼ of the same section Mr. Stoefflet sank a well in June, 1904, to a depth of 96 feet, obtaining a full 2 inch stream of water. The well drained others for a quarter of a mile west and north and had to be plugged. South of the river the conditions are very similar, some wells having ceased flowing, while others still continue, though with diminished head.[2]

Summary.—In a broad way it may be said there is a general shortage of water in the region, but not so severe as in the Swan Creek district, for along the Huron many wells still furnish good supplies or even flow, while in the latter region the failure is almost universal. The causes ascribed for the shortage are similar to those of the Swan Creek area, but with less weight given to the supposed influence of the Grosse Isle well. Cleaning, and more especially deepening the wells generally resulted in an improvement of conditions.

ROCKWOOD REGION.

General conditions.—The Rockwood area includes the region west and southwest of that town and between it and the Swan Creek area, together with the region near the town on the north side of the Huron river. It can be considered as merging into the flowing well areas of Swan Creek and Huron river on the west and with the Detroit river region on the east. The area is mainly over the outcrop of the Sylvania sandstone and yields waters generally free of sulphur. The wells are generally from 20 to 40 feet in depth and are non-flowing, except near the Huron river.

Condition of wells in 1904.—In the following table are given data relating to the condition of the wells as determined by the writer in August, 1904.

[1]Information furnished by W. M. Gregory, August 2, 1904.
[2]Information furnished by Frank Leverett, July, 1904.

CONDITION OF WELLS IN THE ROCKWOOD REGION IN AUGUST, 1904.

Owner.	Location.				Depth.	Head.		Shortage noted.	Remarks.
	T	R	S	Q		Max.	Pres.		
D. Valrance	5	8	17	ne	28	−1	−7	May	Has been dry before. Ascribes loss to Grosse Isle well.
H. D. Valrance	5	8	17	ne	30	+3	−30	.....	Pump gave relief temporarily Ascribes loss to Grosse Isle well.
V. Holmes	5	8	17	ne	.....	+0	−0	May	Water in pipe only.
John Strong	5	8	17	ne	.....	+0	+0	.....	Diminished somewhat.
Royal French	5	8	17	nw	30	+0	−20	.....	Plenty by pumping.
Geo. Case	5	8	18	ne	.....	+0	−0	.....	Nothing done.
Jas. Todd	5	8	7	se	36	+2	−30	.....	Failed suddenly after 32 years. No water by pumping. Lays loss to Grosse Isle well. Two other wells have also ceased flowing.
John Antio	5	8	18	nw	30	−2	−8	spring	One fourth ordinary supply
S. Peters	5	8	7	sw	30	−6	−12	spring	Flowing well also stopped.
Chas. Bancroft	5	8	18	nw	31	+0	−8	1903	Two other wells also failed. Came on again during winter. One stopped temporarily during winter. Stopped again in spring of 1904.
Benj. Bancroft	5	8	18	nw	29	−5	−25	.....	Two wells. Not very low in 1903.
G. Van Riper	5	8	18	sw	36	−5	−14	July	Another similar well. No previous trouble. Lays loss to salt and oil wells.
H. Chamberlin	5	9	13	se	36	−5	.....	.....	Water in bore only.
Philip Bally	5	8	18	sw	40	−5	−12	June	Decreased gradually.
Peter Pilkey	5	8	19	nw	40	−2	.....	early	Low all winter. Water in pipe only.
Mattison	5	8	20	nw	.....	−9	−18	.....	Low all winter.
Mattison	5	8	20	nw	.....	−5	−10	.....	Low all winter
P. Donnelly	5	8	19	ne	.....	−4	−17	.....	Lays loss to Grosse Isle well.
Albert Root	5	8	19	se	22	−10	−14	July	Usually plenty in summer.
John Sigler	5	8	29	nw	22	−3	−12	July	Usually plenty in summer.

Nature of shortage.—The facts set forth show a marked shortage of supplies with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903 when the present shortage first began to be felt. During the winter of 1903–1904 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the individual wells stopped suddenly, the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head, hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest to the west of Rockwood, becoming less near town as the Detroit river is approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

Supposed causes of shortage.—The explanations of the shortage are the same as in the Swan Creek area, with special emphasis on the Grosse Isle well and the Newport quarry. On both of these supposed causes, however, opinions are divided, those not believing in their influence being as positive as those favoring such interference. It was noticeable, however, that the belief in both the quarry and deep well became less firm the nearer they were approached, being held rather by the owners of more distant wells than by those of the nearer ones.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and the shores of Detroit river. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, quite thickly settled and wells are abundant, but probably averaging under 20 feet in depth. In general there has been no trouble with shortage of water, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was as high or higher than is ordinarily the case, as Lake Erie, which controls the groundwater level adjacent to its shores, stood about 15 inches above the normal in the summer of 1904.

WATER SUPPLIES OF GROSSE ISLE.

General conditions.—Grosse Isle is a north-south island about 9 miles long and 2 miles wide lying on the American side of the international boundary in the Detroit river, its center being opposite the town of Trenton, 16 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being situated in the interior, notwithstanding the entire island is under cultivation. The surface is mainly clay or clayey silts, but rock is commonly found not far from river level and in one point, where it rises slightly higher is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of wind mills, no provision being made for filtering. There is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and no one had observed the slightest effect due to the big well at the southern end of the island.

The "Grosse Isle" or "James Swan well."—This well is located on the property of James Swan opposite Snake Island, about three-quarters of a mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the level of the river in 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet but at 450 feet a bigger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart a considerable amount of sulphur to the water as it issues from the pipe, which is recognizable by taste and sulphur deposit on the grass and stones about the well.[1] The water is said to have been cased off during the progress of the drilling from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable

[1] In the analysis as given all the sulphur is reckoned as SO^3. There are soluble sulphides as well as H^2S present, but so far it has proved impracticable to separate them. L.

size. (See plate I.) The flow is calculated at about 50 gallons per second and forms two sizable streams as it flows away from the well. The water was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using the water for a public supply for the island.

REPORT OF ANALYSIS

MADE AT THE CHEMICAL LABORATORY, UNIVERSITY OF MICHIGAN FOR THE STATE GEOLOGICAL SURVEY JANUARY 17, 1905.

Samples marked Grosse Isle water, James Swan's well.
Sampled and analyzed by F. K. Ovitz.

ANALYSIS

Constituents.	Grams per litre.
Silica	0.188
Calcium oxide	7.616
Strontium oxide	0.376
Magnesium oxide	1.212
Sodium oxide	0.292
Potassium oxide	0.112
Sulphuric anhydride	11.871
Chlorine	0.248
Carbon di-oxide	1.550
Iron and alumina	0.014
Loss on ignition	2.006
Total solids	23.972

DECLINE OF THE WATER SUPPLIES OF THE WELLS OF THE LOWER HURON RIVER REGION.

PRESENT CONDITIONS.

The conditions of the walls at the present time have been described in detail in the preceding pages. With the exception of the narrow belt along the shore of the Detroit river, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very slight, while along the Huron river it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large prorportion of the wells going dry and entailing much inconvenience.

BEGINNING OF THE DECLINE.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even then shrinkage of supplies had been in progress for

many years. In his report on Monroe county* he states that while continued drought makes no impression on many of the wells, the flow of others is reduced, or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian waters could be secured was found to be becoming constantly more contracted. Wells in the southern part of Erie township back 3 miles from the lake, which formerly flowed, had then ceased.

The decline noted by Professor Sherzer as having already progressed for some time has continued to the present time. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the non-flowing wells is lower than formerly. In fact, the level of the groundwater in the clayey portions of southeastern Michigan is distinctly lower than it was ten years ago, and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline which has been going on for many years is probably due to a gradual and far reaching change of conditions, the nature of which will be considered on subsequent pages, but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

SUPPOSED CAUSES OF THE DECLINE.—THE GROSSE ISLE WELL.

It is this well which has most frequently been assumed as a cause of the shortage of water in the region under discussion. That it can not be the sole cause is readily shown by the fact that the decline had been going on for many years before its sinking in 1903. That it might be the cause of the special decline in that and the following year did not, however, appear unlikely at first, a special argument being afforded by the behavior of the wells of J. E. Brown of the Swan Creek and of Chas. Bancroft and others of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned coincident with the insertion of the casing, only to cease again after its withdrawal in May, 1904. There are, however, many facts which seem to show that the shortage has no connection with the Grosse Isle well.

Districts affected.—The investigation made by the writer showed, as has been described, that while wells in the Swan Creek and Rockwood districts ceased flowing or failed to yield their usual supplies, other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be very exceptional, which would leave a nearby district unharmed, while seriously affecting more remote districts.

Slope of water table.—With a view of determining the source of the water of the Swan Creek-Rockwood area, the head, or height to which the water would rise, was plotted for each well in the region. It was found that this head showed an increase going west at a rate averaging about 3 feet per mile, indicating a source in the hilly region to the northwest. The increase of head to the west or decrease to the east was regular, there being no local lowering

*Geol. Surv., Mich., Vol. VII., Pt. I., pp. 194.

with a reversed slope *downward* towards the rock, such as would be present if water was being drawn down into the latter through a fissure connecting with the stratum furnishing water to the Grosse Isle well. (See Fig. 3.)

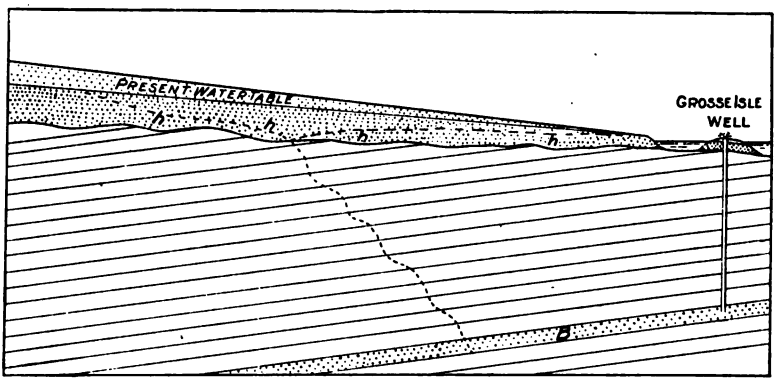

Fig. 3.—Ideal section across Grosse Isle and the mainland.

B is the previous water bearing bed from which the Grosse Isle well draws, and the line *h h h* shows the sort of form the water table should take were the surface strata connected therewith by the fisure shown by the dotted line leading down to *B*.

Geologic structure.—The precise point where the main water-bearing bed of the Grosse Isle well outcrops and where its supply of water is derived can not be stated. The rocks incline regularly to the northwest (or rise to the southeast) at a rate of perhaps 20 feet to the mile. On the basis of this dip it would seem probable that the water bed, which has a depth of 450 feet at the well, would come to the surface somewhere west of Leamington, Ontario. In the Huron river region, however, it would be even deeper than at the well, probably in the vicinity of Carleton, being nearly 800 feet below the surface. The chance of there being any fissure through all this thickness of strata, by means of which connection between the deep water beds and the surface wells might exist, is very improbable. On the other hand water can pass downward along the bedding planes with the greatest ease. Such is probably the case, the water being derived from the Ontario region rather than on the American side of the river.

Volume.—A strong impression is left on the mind of one visiting the Grosse Isle well by the immense volume of its flow, which is calculated to be between 45 and 50 gallons or over a barrel a second. When, however, it is recalled that the region in which the failure of the wells has been attributed to the Grosse Isle hole has an area of over 100 square miles, it will be seen that the amount which could be taken each second per square mile is not over half a gallon, or less than a thousandth part of a gallon per acre. The amount ordinarily taken from a square mile by the flowing wells of the Swan Creek and Rockwood districts was much more than this, in fact the taking of a thousandth part of a gallon per acre each second would probably not have a noticeable effect on the flows.

Head.—The most convincing reason why the Grosse Isle well can not have affected the Swan Creek-Rockwood wells lies in a comparison of the heads of the water in the two localities. The head of the Grosse Isle well is 25 feet

above lake level, or approximately 597 feet above sea level, while that of a considerable number of the Swan Creek and Rockwood flows is less than this amount. In other words, the head of the Grosse Isle well is greater than many of the wells under discussion, and the water, if any connection existed between the two, would not be drawn from the shallow wells, but rather forced up into them.

Summary.—The evidence at hand gives no indication of any connection between the shortage of the shallow wells and the flow of the big Grosse Isle well, but affords on the other hand many indications that such is not the case. The supposed connection with the Grosse Isle well of the loss of water in the Brown and Bancroft wells in 1903 is the result of mere coincidence, the failure simply happening to take place at the height of the dry season of that year. That they should have failed in the still dryer season of 1904 was to be expected. The conditions were almost ceratinly local, as other wells in the vicinity were not similarly affected at the same time.

NEWPORT QUARRY.

The under-drainage caused by the quarry was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions investigated.

The quarry is located just east of the tracks of the Lake Shore and Michigan Southern railroad at Newport and a few feet north of Swan Creek. The quarry is 200 to 300 feet across and is excavated to a depth of 18 feet in the limestone, which is reached after 10 or 15 feet of stripping. The creek flows on top of the rock surface, 18 feet above the bottom of the quarry, and is separated from the excavation by a small dike. Water enters at various points in small amounts, but is easily removed by pumping at a rate of about one-half a gallon a second.[1] A part of the wells near at hand have been affected, but the decrease in the water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted.

The small amount of water entering the quarry is in itself an indication that no extensive area is being drained, while the fact that only a part of the adjacent wells are effected while those a short distance away are unaffected, shows that even in its vicinity, the quarry may be neglected as a factor in the shortage of the water supply.

DEFORESTING THE LAND.

The existence of forests in a region, while not affecting the amount of water falling on the ground, tends to prevent its escape into the streams with the rapidity with which it runs off of non-timbered lands. By holding it back, even for a few hours, considerable greater quantities are allowed to soak into the ground than would otherwise be the case. Evaporation from the surface is also retarded, the ground remaining wet for much longer periods in wooded than in unwooded lands. The cutting of the timber must, therefore, be accepted as a factor in the general decrease of the supplies of the region, but was effective only in the earlier days. It can not be considered as one of the immediate causes of the sudden shortage of 1903–4.

[1]Four inch pipe, one-half full, but ejected with slight force.

DRAINAGE BY DITCHES.

The region under discussion is exceedingly flat, and because of its clayey soil and poorly developed stream systems was originally poorly drained, the low sags often holding water or remaining wet for long periods. All this has been gradually changed through drainage by ditches, with the result that much land has been reclaimed. The process, however, has not been without its drawbacks, for the ditches rapidly carry off much of the water which had previously soaked into the ground to become a part of the groundwater body. The result has been a gradual depletion of the groundwater especially within the past few years, so that the beginning of the present drought found an inadequate reserve supply in the ground.

DRAINAGE BY STREAMS.

The level of streams generally determines that of the groundwater in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron river and Swan Creek were unusually low and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. The Huron river, being a longer stream, and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which falls within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is most marked along its course rather than in any other part of the region.

EARLY FROST OF 1903.

This appears to have been an important factor in bringing on the present acute shortage. According to the official records the permanent freezing of the ground took place on November 17th, which was before the heavy autumn rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and spring months. This was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the groundwater was at an unusual low stage.

DEFICIENCY OF RAINFALL IN 1904.

Because of the fact that the ground was frozen during the autumn and winter the ground was in much the same condition at the opening of the spring of 1904 as it was at the end of the preceding summer, and as month after month during the present summer went by with deficient ranifall the shortage began to be severe.

The shortage of rainfall is brought out by the following table which gives the precipitation by months for 1904. Detroit lies about 25 miles northeast of the area, Dundee about 20 miles southwest, Eloise less than 15 miles north, and Ypsilanti 20 miles northwest.

RAINFALL IN THE VICINITY OF THE LOWER HURON RIVER REGION IN 1904.

Month.	Detroit.		Eloise.		Dundee.	Ypsilanti.	
	Actual.	Normal.	Actual.	Normal.	Actual.	Actual.	Normal.
	In.	In.	In.	In.	In.	In.	In.
January	3.34	1.94	3.98	1.69	5.37	4.54	1.90
February	2.55	2.33	00	2.16	4.06	2.98	2.46
March	4.09	2.29	00	3.01	5.45	4.92	2.45
April	1.65	2.24	1.01	1.32	2.36	1.66	2.24
May	2.36	3.51	1.19	3.27	3.06	2.58	4.09
June	1.08	3.69	.79	3.26	1.30	.56	4.25
July	2.94	3.36	2.52	4.16	2.84	3.03	3.33
August	3.20	2.71	3.69	1.95	4.73	3.92	2.14
September	4.23	2.47	3.83	2.61	4.20	6.21	2.86
October	.86	2.53	00	2.61	.82	1.09	2.64
November	.19	2.69	00	2.38	.05	.09	3.23
December	1.83	2.57	1.88	2.23	2.53	1.96	2.38

The low rainfall, which in the spring of 1904 varied from half to somewhat more than half of the usual amounts at the stations in the table was, on the whole, even less in the lower Huron river region itself. The deficiency of rainfall following as it did an autumn and winter during which little water was absorbed, owing to the frozen condition of the ground, and back of that the dry season of 1903, is ample to explain much if not all of the observed shortage.

Although considerable rain fell in July, and even more than the normal in August, it came largely as short heavy showers, and the water instead of soaking into the ground, as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell.

SHORTAGE IN OTHER REGIONS.

While the shortage was made manifest in the lower Huron region much sooner than elsewhere, later in the summer the drought became severe throughout all the states bordering the Ohio and eastward to New England, and much trouble and inconvenience were the result. In the other regions the failure was due simply to the shortage of rainfall, the complicating conditions that were present in the Huron region and served to make the scarcity of water more severe being absent.

CONCLUSIONS REGARDING SHORTAGE.

No evidence was found to show that the Grosse Isle well had affected any of the wells whatever, nor that the Newport quarry was a factor in the failure of wells other than those situated within a few hundred feet of it The deforesting of the region has been a factor in the general decrease of supplies in the past, but had no immediate connection with the present shortage. The ditching of the region was a prominent factor in the gradual depletion of the groundwater body so that when the usual fall rains were prevented by frost from being absorbed and the winter was followed by a summer of exceptional drought, the conditions were ripe for the failure of water which followed.

FUTURE PROSPECTS.

The failure of the wells being due largely to the severe drought of 1903–1904 it is probable that the return to the normal rainfall will result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or perhaps a succession of wet years occur.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey materials when dried out may, to a certain extent, crumble and become more or less clogged, so that their capacity for carrying water is lessened or destroyed even when the ground again becomes soaked. The return in any case will probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

REMEDIES.

The wells in the lower Huron river region obtain their supplies in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more or less jointed and open portion of the rock because there is less resistance to its flow through such crevices and openings in the rock itself than through the compact clayey deposits which generally overlie the rocks of the region. In its passage the water takes up sulphur and other mineral matter contained in the rock, its quality thus being changed from its relatively pure condition when it left the drift.

It has been shown in the discussion of the wells of the region that deepening has almost invariably met with at least partial success, especially where the wells have been sunk deeper into the rock. Throughout the entire region, however, the wells are unusually shallow, even for the surface type, a depth of 50 feet being exceptional. In many other regions in Michigan nothing is thought of going 50 to 100, or 150 feet in search of water. It is almost certain that wells of such a depth would in the lower Huron river region yield permanent supplies. Until such wells, or at least wells entering some distance into the rock, are sunk a supply adequate to the demands in times of drought cannot be expected.

DESIRABILITY OF LAWS REGULATING DEEP OR ARTESIAN WELLS.

GENERAL STATEMENT.

The desirability of regulating the use of a commodity belonging in a sense to the public at large is very generally recognized. This has been especially true of petroleum and gas, many states having stringent laws against their waste. Regulations governing the casing of wells in use, the plugging of wells about to be abandoned, and forbidding the free flow of gas, are to be found among the enactments in most states in which such commodities are found and have been of much assistance in securing a more intelligent management of wells and the husbanding of their products.

Water, even to a greater extent than oil and gas, can be regarded as a public commodity, and although its value is less than either of the former, it is nevertheless an important factor in many businesses. Because of the excessive cost of the deep water wells, which is as great as those sunk for oil and gas, the obtaining of large amounts is, however, even more essential. The great importance of obtaining cheap supplies will be appreciated when it is recalled that among the competitors of almost every manufacturing establishment there will always be some who will be able to obtain abundant supplies of the best quality at almost no cost above that of pumping.

Moreover, the occurrence of groundwater can no longer as formerly be regarded even at law as anything mysterious, there being at the present time many geologists and engineers familiar with its occurrence and the character of its movements. For this reason it should be entirely possible to make intelligent regulations by legislative enactment for controlling its use and preventing its waste.

LIMITATIONS TO AMOUNT OF GROUND WATER.

Percentage of absorption.—The rainfall throughout the United States is said to average about 30 inches per annum, that of Michigan being from 30 to 35 inches. Of this, however, not all is absorbed by the ground, large portions being carried off by the streams, or removed by evaporation. The actual amount absorbed by the ground is probably but a very few inches.

Availability of groundwater.—Groundwater occurs under a great variety of conditions which have an intimate relation to its availability. It may occur in the pores of open sands or sandstones, in cavities in limestones, along bedding planes of slates, and in fissures in any of the consolidated rocks. In sands, or in sandstones and other similar rocks, the body of the material is saturated as a sponge, and a well penetrating it at almost any point will obtain a supply. In the case of cavities, bedding planes, or fissures, the water is likewise given up with ease when encountered, but, because of the fact that it occurs only in a limited number of openings, the position of which can not be predicted, failures frequently result, and the supplies when found are generally of less volume and permanency than in the sandy beds. Notwithstanding the density of clay much water is contained in it. This, however, because of the fine grain of the containing material, is held firmly in-

stead of being given up readily to the wells as in the case of other materials. In fact a well may penetrate a clay containing a high percentage of water and yet be able to obtain hardly a drop. The same is true of certain of the finer quicksands, but for another reason, in the latter cases the material being so fine that it unites to form a mixture with the water which soon clogs the wells, and from which the water can not be separated. Much of the water which penetrates the rocks is carried to too great a depth to be reached by ordinary wells.

From the above it will be seen that even the small quantity absorbed by the soil or rocks is still further reduced by the amounts held in clay and similar material, by the amounts entering the deep lying rocks, and by the frequently localized nature of the occurrence of the water, as a result of which wells can be obtained only at certain favored spots.

Supply not inexhaustible.—When a single well penetrates a thick, porous water-bearing bed the supply may be equal to the maximum capacity of the well, but as other wells are sunk the demand rapidly increases and soon becomes greater than the supply, the wells showing the effect of shortage by a decrease in this volume or by a lowering of their head. This is well illustrated by the wells of the Chicago area. When the first wells were put down to the Potsdam sandstone the flows were large, the water rose as high as 80 feet above the surface, and the supplies appeared inexhaustible. As the wells multiplied, however, the amount obtainable by each became much less and the heads were so reduced that the wells rarely flowed. The same has been true of many other artesian districts; in fact, it may be laid down as a general law that no pool is inexhaustible. On the contrary each pool has a definite volume from which every well takes just so much, thereby diminishing the total available supply.

Replenishment of supplies.—The groundwater supplies are replenished from rainfall. When the wells drawing upon the underground supplies are few in number the water may be replenished as fast as it is removed by the wells, but when the number of wells is large the replenishment does not keep pace with the withdrawal. The replenishment is not altogether a question of rainfall, many other factors entering into the question, among which the conditions at the outcrop and the rate of water movement are the most important. The last is of great importance for if the rock be sufficiently fine-grained the water will enter and move but slowly, even though the outcrop be constantly covered by water.

Danger from the free flow of wells.—The water in the rock represents the accumulation of years, and a well may draw off in a few hours water which it took months to get together. It is like pulling the plug out of the bottom of a barrel into which a stream of water is running, to allow a well to flow freely. Of course the only value of water lies in its availability for the use of man, and its employment for all legitimate purposes should be encouraged. It is only the useless waste of supplies that may soon become of great value that should be forbidden. Artesian water should no more be allowed to run to waste than should a young growth of timber be allowed to be burned simply because it does not at the present moment happen to be marketable.

Danger from improper casing.—In the same way that waste may take place from the free flow of a well at the surface, water from an underlying stratum may if the well is uncased rise and pass off laterally into an overlying non-saturated layer. In the same way the water from an upper stratum may pass downward and be absorbed by a lower stratum. In either case

the loss is a real one, as real as if it had taken place at the surface, for the result is that the confined water, which from the very fact of its confinement furnishes the most ideal conditions of supply, becomes dissipated through a large amount of material, in no part of which is it probable will it be present in economic amounts.

SUMMARY.

Groundwater is properly a commodity belonging to the public at large, and is an asset of recognized value. The amount is not unlimited at any point, and any decrease in its volume means a reduction of assets and a permanent loss to the community. It is difficult to prove damages to surrounding wells caused by free flows, but when it is remembered that the underground supply is limited in amount, and that the available supply is being constantly decreased by such flow, it is readily seen that the loss is none the less real. A freely flowing well is in itself a proof of such loss, and should be forbidden, except where reasonable use is made of it.

RECOMMENDATIONS.

(1) An enactment should be passed making it unlawful to permit water to escape where no use is made of it regardless of the size of pipe or volume of flow, and a penalty should be fixed for its infraction.

(2) An enactment should be passed making it obligatory in case of abandoning a well over two inches in diameter to securely plug it above and below each water horizon, or to fill the hole with cement or other impervious material, with a penalty fixed for its infraction as before.

(3) An enactment should be passed requiring that wells when not in use shall be closed down until not more than an inch stream is flowing, a penalty to be attached for infraction as before.

(4) Provision should be made for restraint of flows by injunction on application of parties presenting evidence of waste.

(5) The power of entering private property for the purpose of determining questions relating to waste should be given to the proper officials.

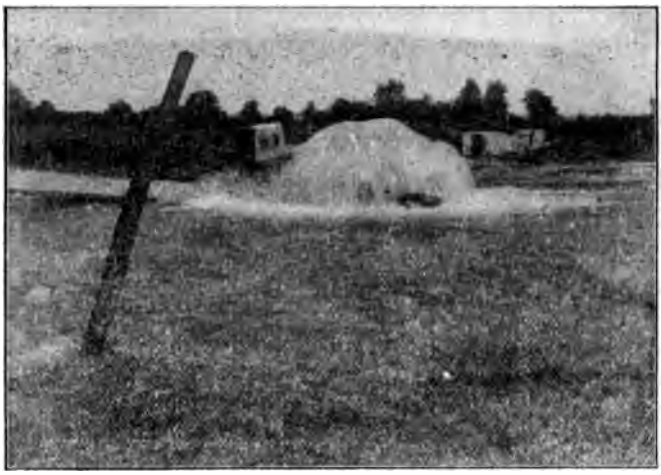

PLATE I.—VIEWS OF THE FLOWING WELL AT GROSSE ISLE.

A GEOLOGICAL RECONNAISSANCE

ALONG THE NORTH SHORE OF LAKES HURON AND MICHIGAN

BY ISRAEL C. RUSSELL

OFFICE OF THE STATE GEOLOGICAL SURVEY,
Lansing, Michigan, Feb. 7, 1905.

To the Honorable the Board of Geological Survey of the State of Michigan:

Gentlemen: I transmit herewith for publication in the annual report of the Board for 1904 the report of Prof. I. C. Russell of Ann Arbor on his field work last summer with accompanying map. It gives not only an account of some interesting features, eskers and drumlins, which have hardly been noticed in that region before, but also notes on the soils and agricultural possibilities of the region. It is worth noting that according to Mr. Russell the drift coating over the bed rock surface is rarely thick, so that even in the sandy areas it is not probable that the ground water level is very far down. The unmitigatedly sandy areas he does not find to be very large, though all the till is sandy owing to the prevalence of sandstone to the north.

The presence of interglacial lake clays is both scientifically and practically interesting.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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INTRODUCTION.

The region discussed in this report includes a strip of country varying from about six to thirty miles in width, bordering lakes Huron and Michigan on the north, and extending from Drummond Island westward to the Michigan-Wisconsin line at the mouth of Menominee river. Its northern limit is an east and west line situated six miles north of the 46th parallel of latitude. The area thus defined is indicated on the index map forming Plate I.

The immediate occasion for a re-examination of the geology of the region designated above, was the preparation of a map of the surface geology of Michigan to be published by the Geological Survey of Michigan, on a scale of six miles to an inch, to be printed on nine sheets. Six of the sheets include the Southern Peninsula of Michigan, but overlap onto the Northern Peninsula in such a manner as to embrace the row of townships next north of the 46th parallel of latitude. In order to facilitate the publication of the sheets including Southern Michigan it became desirable to map the surface geology of the strip of country mentioned above. This task was assigned to me by A. C. Lane, State Geologist of Michigan, and occupied my time from July 4th to September 10th, 1904. The region traversed is indicated on the map forming Plate XVI which obviates the necessity of describing it in detail. Owing to the area of the country to be examined, approximately 2,400 square miles, and the comparatively brief time available for the work, nothing more than a reconnaissance could be undertaken. In judging of the value of the results obtained, the rader is asked to bear in mind not only the area of the region examined and the time devoted to the task, but also the fact that by far the greater part of the country traversed is still clothed in forest and much of it occupied by almost impenetrable swamps.

Favorable to geological exploration, on the other hand, is the fact that the portion of the Northern Peninsula under consideration, is crossed by several railroads; containg several cities, as Detour, Mackinac, St. Ignace, Manistique, Gladstone, Escanaba and Menominee, besides several villages, lumber camps, etc.; and at many localities on the shores of lakes Huron and Michigan is visited by steamboats. St. Ignace, Mackinac Island, Les Cheneaux Islands, Detour, etc., are frequented each summer by hundreds of people in search of rest and recreation, and contain a large number of summer hotels. These evidences of civilization, however, are not as great an aid to exploration as they probably seem to one who has not attempted to traverse the region indicated. The leading industry to the east of Gladstone and Escanaba is lumbering, inclusive of the cutting of pulpwood and railroad ties. As is well known, the practice in this connection even at the present day, is to fell such trees as are wanted and leave on the ground the branches and other portions not of immediate commerical value. Fires usually follow the lumbermen, and a dense growth of trees and shrubs springs up

in the course of a few years on the fire-swept districts, which obscures the land and renders traveling even on foot exceedingly difficult.

The westward end of the portion of Michigan included on the above map is more favorable for agriculture than the part of the State bordering lakes Huron and Michigan on the north, and large areas particularly on Garden Peninsula, (situated between Lake Michigan and Big Bay de Noc) and in Delta and Menominee counties, lying principally to the west of Green Bay, have been cleared of their formerly dense forests, and are under cultivation. In this section wagon roads are quite numerous, comfortable farm houses abundant and the people, as is the case throughout the entire region traversed by me, most hospitable and obliging. Several railroads radiate from Escanaba and Gladstone, which faciliate geological work not only by furnishing means of transportation, but on account of the numerous excavations made during their construction. Geological work can, therefore, be carried on to the west of Green Bay more satisfactorily than in much of the eastward portion of Northern Michigan.

While the present report is based principally on personal observations, the writings of previous students of the geology of the same region have been freely used. A brief account of these writings will I think be interesting to the reader.

PREVIOUS PUBLICATIONS.

The portion of Michigan adjacent to lakes Huron and Michigan on the north, is by no means a new field to the geologist. It was first systematically explored in reference to its geology in 1850, while yet a portion of the Lake Superior Land District of the United States, by Messrs J. W. Foster and J. D. Whitney. Associated with this survey, were Messrs E. Desor, James Hall and Charles Whittlesey, each of whom made important contributions to previous knowledge concerning the geology of Northern Michigan. Desor in particular devoted his attention to the sands and clays which form the principal part of the soils and sub-soils, and began the study of the old beaches which record former and great changes of level of the water in the Great Lakes basin. For this task he was well prepared by previous work in Europe, having been associated with Agassiz in the study of the existing glaciers of Switzerland, and taken part in the interpretation of the records of ancient glaciers in Germany and adjacent regions. It was about this time that the importance of glaciers as agents in modifying the earth's surface began to claim the attention of Agassiz, Charpentier, Forbes, Guyot, De Saussure and others in Europe, and the foundation was laid for a systematic study of the records left by ancient glaciers in various parts of the world. Desor fresh from the land where these matters first claimed serious consideration, came to America as did Agassiz, and Guyot, and with them assisted in stimulating an interest in glacial geology in this country which has continuously increased to the present day, and is one of the chief divisions of the earth's history now receiving attention from the geologists of both Canada and the United States. On arriving in America Desor became connected with the U. S. Coast Survey, and was thus enabled to continue the study of lake shore topography, etc., previously begun in Europe, which gave him valuable training and enabled him to recognize the significance of the several abandoned beaches which form such a conspicuous feature of the slopes bordering the Great Lakes. Desor was associated wtih Forbes and Whitney during 1849 and 1850, and was enabled to examine in

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a general way nearly all of the Northern Peninsula of Michigan, which was thus made classic ground to glacial geologists. Besides several papers dealing with the surface geology of Northern Michigan, published in the scientific journals of Europe and America, he furnished two reports on his observations, which were embodied in the reports made by Foster and Whitney to the Commissioner of the General Land Office.[1] Much use has been made of Desor's observations while writing the present report.

In the second report by Foster and Whitney there is an article on the ancient and present beaches of Lake Michigan, and a chapter on the observed fluctuations in elevation of the surfaces of the Great Lakes by Charles Whittlesey, which contains many data of value not only in reference to the shoaling or deepening of harbors, but of use in demonstrating that a secular change in elevation, or a tilting, of the rocks of the region where the Great Lakes are situated, is in progress. The modern changes about the shores of the Great Lakes and the light thus furnished in reference to the history of the abandoned beaches now high above the surfaces of the lakes, were discussed by Whittlesey in "Contributions to Knowledge," published by the Smithsonian Institution and elsewhere.[2]

The geology of the stratified rocks, principally dolomite and limestone, beneath the surface covering of unconsolidated debris in the part of Michigan under consideration, was studied by James Hall during the Foster and Whitney survey, and later by Carl Rominger, State Geologist of Michigan. In the reports of Hall and Rominger, the positions which the rocks now occupy, the tract of county each formation immediately underlies, and the abundant records of the life of the time during which the several formations were deposited, received special attention. The writings of Hall and Rominger in reference to the older chapters in the geological history of Michigan are fully as interesting and instructive as the story of the much more recent changes described and discussed by Desor and Whittlesey, and are important contributions to knowledge. The report by Rominger, in particular, dealing with fossil corals, and contained in volume III of the reports of the Michigan Geological Survey, should be of great educational value to the inhabitants of the Northern Peninsula, since it contains descriptions of the marine life which flourished in that region when it was covered by tropical seas. Fossil corals occur in abundance especially in the Garden Peninsula, where they not infrequently form a large part of the stone walls built about the fields of the farmers. These beautiful objects awaken interest even in the minds of the unlearned on account of their peculiarities of shape and structure, and attract the attention of children. With the aid of Rominger's report they can easily be made stepping stones to a knowledge of nature, as well as walls about meadows and pastures.

Since Desor and Whittlesey directed attention to the glacial deposits and old lake beaches of Michigan, much interest has been taken in the later chapters of the earth's history preserved in this and adjacent regions, by the people of Canada and the United States, and a large body of literature bearing on the subject has been published. While the results of nearly all of these studies have a direct bearing on the later geological history of the

[1]Foster, J. W. and J. D. Whitney "Report on the geology and topography of a portion of the Lake Superior Land District, in the State of Michigan. Part I. Copper lands." Executive Document No. 69, House of Representatives, 31st Congress, 1st session. Washington, 1850, pp. 186–218.
"Report on the geology of the Lake Superior Land District. Part II. The iron region together with the general geology." Executive [Document] No. 4, Senate, Special Session, March, 1851, Washington, 1851, pp. 232–270.

[2]Reference to the publications of Whittlesey and Desor, may be found in, N. H. Darton's Catalogue and index of contributions to North American geology, 1732–1891, Bulletin No. 127, U. S. Geological Survey, Washington, 1896.

region described in this report, those most intimately connected with it are the writings of F. B. Taylor, of Fort Wayne, Indiana, who has devoted much time to the study of the abandoned shore lines of the Great Lakes and especially of the region about Mackinac Island and the northern border of Lake Michigan. The numerous papers by Taylor are for the most part listed in bibliographies of North American geology[1] and will be referred to many times in the following pages.

Of the many papers relating to the Great Lakes in general, and to their geological history, which refer to the changes recorded by former water-bodies about the northern shores of lakes Huron and Michigan, perhaps the most suggestive is one by G. K. Gilbert[2] dealing with the movements in the earth's crust which has recently affected the entire Great Lakes region, and are still in progress. A knowledge of the movement or tilting of the land now in progress in the region of the Great Lakes is important not only to the engineer who has charge of harbor improvement, but of great assistance to the geologist who endeavors to account for the many changes in water-levels that have taken place and are recorded by abandoned beaches which are no longer horizontal.

The several reports and papers mentioned above, and still others, referred to later, have been of great assistance while writing the present report. In this connection mention should also be made of the splendid charts of the Great Lakes published by the U. S. War Department.

OUTLINE OF GEOLOGICAL HISTORY.

The portion of the earth's history recorded in the rocks and in the topography of the part of Michigan adjacent to lakes Huron and Michigan on the north, has two distinct divisions; one dealing with the solid rocks of ancient date, the other with the superficial layer of clays, sand, soils, etc., of comparatively recent origin which rest on the surfaces of the hard rocks.

In the older chapter the records pertain to a time when the site of Michigan was covered by the waters of ancient seas, over the bottoms of which deposits of sand and mud were spread out in horizontal layers. These beds have since been hardened into sandstone, limestone, dolomite (magnesian limestone) etc., but still retain fossil shells, corals, crustaceans, etc., which reveal the nature of the life inhabiting the ocean during the Paleozoic or ancient division of geological time. The younger chapter of the geological history deals principally with the great ice invasion, termed the Glacial Epoch, during which the site of Michigan, together with a vast region about it, was buried beneath glaciers in much the same manner that Greenland is sheltered with ice at the present day. Intimately connected with this ice invasion were lakes, at times of wider extent than the present Great Lakes, which occupied the same basins and left conspicuous beach lines about their border. Each of these two divisions of the geological history of Michigan, although conspicuously different in nearly every detail, is full of interest even to the general reader, and in each case, also, has a direct and important bearing on human affairs.

It is instructive to tabulate the chief divisions of the two great chapters

[1]Weeks, F. B. Bibliography of North American geology, paleontology, petrology and mineralogy for the years 1892–1900, inclusive. U. S. Geological Survey, Bulletin No. 188, Washington, 1902.

[2]Recent earth movements in the Great Lakes region, U. S. Geological Survey 18th Annual Report, pt. II, pp. 595–647; republished in part in National Geographic Magazine, Vol. VIII, pp. 233–247; and also in Annual Report of the Board of Regents of the Smithsonian Institution for 1898, Washington, 1899, pp. 349–361.

of geological history just referred to, and to indicate the nature of the records on which their interpretation depends. Such a summary reads as follows:

OUTLINE CHART OF GEOLOGICAL RECORDS.

Geological Time.	*Nature of the Records.*
PRESENT EPOCH.....	Lake beaches still being formed; river silts and sands, peat, marl, etc., now being deposited or still growing; river valleys still being deepened; lake beaches formed since the Glacial Epoch and now abandoned; deposits now being made in lakes, etc.
GLACIAL EPOCH.....	Abandoned beaches of ice-dammed lakes. Glacial striæ and other markings on rock surfaces. Glacial deposits, as till or boulder clay, occurring as a surface blanket over the hard rocks, and in places forming lenticular hills or drumlins. Gravel and sand deposited by glacial streams, such as irregular ridges or eskers and sand plains.
A long time-interval during which Michigan was a land area and subject to erosion.	
PALEOZOIC ERA.... Monroe Period..... Niagara Period..... Lorraine and Utica Period..... Trenton Period..... Calciferous Period...	Mostly marine limestone, usually magnesian, in nearly horizontal beds, and containing fossil shells, corals, crustaceans, etc.

As this schedule suggests, a convenient plan for presenting a popular account of the geological history of the portion of Michigan under consideration, is to give: First, a brief summary of what is known concerning the older or Paleozoic formations, and a free interpretation of their history, or the hard-rock geology as it may be termed. Second, a discussion of the nature, mode of origin, etc., of the superficial blanket of rock-waste which rests on the hard rocks, or the surface geology. Of these two divisions, chief attention is here invited to the surface blanket of rock-waste inclusive of soils and sub-soils, for the reason that it is everywhere in sight, and in the region examined is of greater economic importance to man than the hard rocks beneath, as it furnishes the basis for agriculture, and forms the surface in which forests are rooted.

THE HARD-ROCK GEOLOGY.

The rock formations beneath the unconsolidated surface covering of glacial deposits, lake clays, etc., of Michigan—with the exception chiefly of the igneous rocks, granite, schists, etc., of the iron and copper regions of the Northern Peninsula—are marine deposits and all belong to the Paleozoic, or most ancient of the formations at present known which contain records of life.

Within the area represented by shading on the map forming Plate I, the formations of older date than the Glacial Epoch all belong to the Silu-

rian (or Ordovician and Silurian of some schemes of classification) and include the following sub-divisions as recognized by the Geological Survey of Michigan, namely, in descending order, the Monroe, Niagara, Lorraine and Utica, and Trenton, formations. These names have been applied to sheets of rock, mostly limestone and dolomite (magnesian limestone) which in the region bordering lakes Huron and Michigan on the north, have an aggregate thickness of about 1,800 feet from the top of the Monroe to the base of the Trenton and are inclined downward or dip southward at low angles. The dip at most localities is so gentle that the beds of rock appear to be horizontal. Owing to the dip of the formations and the manner in which they have been eroded, they come to the surface in a series of concentric belts, concave to the south, as indicated on the geological map of Michigan forming Plate III.

The Monroe Formation: The rocks thus designated are about the equivalent in age of the Manlius and Salina[1] (and Lower Helderberg of some authors) formations of New York, which include the salt and gypsum deposits near Syracuse. Similar rocks occur in Northern Ohio and southeastern Michigan where they also contain beds of salt and gypsum. In Northern Michigan this formation occurs at the surface on the St. Ignace Peninsula, Mackinac Island, Bois Blanc and other neighboring islands, as was made known by James Hall in 1850,[1] and much information concerning it is recorded in his contribution to Foster and Whitney's report already referred to. The light colored limestone forming the upper portion of the conspicuous precipices about the border of Mackinac Island and appearing in the St. Ignace Peninsula and on Bois Blanc, were identified by Hall as about the equivalent of the Helderberg formation of New York. Beneath this somewhat massive limestone and exposed at the water's edge about Mackinac Island, and in a similar position on the margin of the St. Ignace Peninsula, are gypsum bearing beds having the stratigraphic position of the Salina formation of New York. These gypsum bearing beds form the surface on the northern portion of Mackinac Island and outcrop throughout a considerable area a few miles north of St. Ignace. When at or near the surface their presence is indicated by a multiform topography characterized by a succession of irregular hills with equally irregular hollows between, and as a rule the absence of surface streams. These peculiar surface features are due to the removal of the more soluble portions of the deposit and especially the gypsum (hydrous calcium sulphate) which they contain. This mineral occurs in irregular beds, and mingled with it is a similar mineral known as anhydrite or the anhydrous calcium sulphate. Possibly beds of salt like those present in rocks of the same age near Detroit, have also been dissolved away, but borings seem to indicate that they do not extend so far north. The peculiar roughness of surface referred to, is confined to the localities where the Salina formation is present and is not found elsewhere in the portion of Northern Michigan under consideration.

The rock, mostly impure limestone, at the top of the gypsum bearing formation and marking the passage into the overlying formation, is peculiar, inasmuch as it consists of angular fragments of limestone inclined in all directions and cemented into a compact mass by carbonate of lime which has been deposited in the cracks and crevices between them. This *breccia* is well exposed in the rocky ridges in the western portion of the town of

1 The New York correlation was made by Hall. The presence of gypsum, etc., and a very fair description of the formations associated with it, however, had already been given by Bigsby in 1822.

QUARRY IN JOINTED NIAGARA LIMESTONE, DRUMMOND.

July 24, 1904.

St. Ignace, and at the "Sugar Loaf" and other localities on Mackinac Island. An explanation of the origin of the breccia, so far as I am aware, has not been offered, although Hall directed attention to it and judging from the statements made in his report, seemed to consider it as evidence of an unconformity,[1] that is, the occurrence of an interval during which the lower formation was exposed to the air and broken and eroded before the rocks resting on it were deposited. The fragments of limestone in the breccia, however, are sharply angular and not rounded as is nearly always the case with stones that have been weathered, or removed and re-deposited by water. The nature of the breccia and its occurrence above strata containing easily soluble beds of gypsum,—and of anhydrite which in the presence of water is prone to change to a hydrous condition, accompanied by an increase in volume—suggests that the fracturing and displacement of the rocks may be due to the removal of material in solution, and to changes in volume caused by the hydration of the anhydrite. Remembering that the present surface of the St. Ignace Peninsula, etc., has been exposed owing to the removal of very considerable depths and probably many hundreds of feet of rock, it is evident that the solution of beds of gypsum or the alteration of the anhydrite, at any time subsequent to the consolidation of the formations resting on it, would lead to movements, and particularly the settling and fracturing of the rocks above the gypsum-bearing layers, which would become broken, and displaced and if re-cemented would form a breccia. The above suggestion may perhaps lead future visitors to the region about Mackinac to examine the rocks attentively with the view of discovering evidence which will sustain or disprove the hypothesis here proposed.

As has been described by Hall, the limestone of Onondaga age in the St. Ignace region, like the limestones or dolomites of similar age in New York and Southeastern Michigan, are frequently vesicular owing to the removal from them of material more soluble than the main bulk of the rock. The cavities thus produced are frequently angular or gash-like and as has recently been shown by E. H. Kraus, have resulted in many if not all instances from the solution of crystals of celestite (strontium sulphate) with which unweathered rocks in the same formation are frequently changed.

Gypsum has been found on the St. Ignace Peninsula in considerable abundance, and is exposed at certain localities on Mackinac, St. Martin, and Goose islands, but is not known to occur at these localities in sufficient quantity and of the requisite purity to be of commercial importance.[2]

While rocks of the same age as those forming at the St. Ignace Peninsula and neighboring islands, are sometimes rich in fossils, those outcropping to the north of the straits of Mackinac are mostly barren of such remains and offer but little inducement to collectors of the relics of ancient life.

The Niagara Limestone: The rocks corresponding in age with the Niagara and Clinton formation of New York and consisting almost entirely of light colored, white or bluish, magnesian limestone or dolomite, are the most widely distributed and in several ways the most important of the formations exposed in the region treated in the present report. They extend in a curving bed concave to the south, (see Plate III) and with an average width of about fifteen miles, from Drummond Island westward to the end of Garden Peninsula. The thickness of the sheet according to Hall, is about 350 feet,[3]

[1] Foster, J. D. and J. D. Whitney, Report on the geology of the Lake Superior Land District, Washington, 1851, p. 162.
[2] See, however, vol. 9 of the Reports of the Michigan Geological Survey.
[3] Probably more rather than less. See Annual Report of the Geological Survey of Michigan for 1903, pp. 114–122.

and its inclination or dip is southward at a low angle, in general amounting to a descent of about thirty-five or forty feet to a mile. In a general way the dip changes from southwest in the vicinity of Detour to southeast on the Garden Peninsula, indicating as will be discussed more fully on a subsequent page, that this immense sheet of rock, in common with other and adjacent sheets both above and below has been depressed in the region occupied by Southern Michigan so as to have a saucerlike shape.

The Niagara limestone was deposited in a shallow ocean, in which the conditions were for the most part favored the growth of corals, mollusks and other invertebrate animals which live in the open sea. The condition changed, however, from time to time, and mechanical sediment such as mud and sand were carried by currents far from shore and mingled with the organic debris of the open waters. These changes are recorded in the nature of the rocks and by the relics of life they contain. Throughout the region under consideration, the land during the Niagara period was sufficiently distant to prevent the detritus brought from it by streams from making conspicuous deposits. The material accumulated on the oceans floor was mainly supplied by the hard parts of animals and especially corals, which lived in its waters, although clayey sediments derived from the land did at times interfere with or modify the development of the living organisms. The more purely calcareous layers of rock or the ones with no appreciable admixture of argillaceous matter, abound in corals, as remarked by Hall, and appear to have been coral reefs, which even now occupy their original positions. In many instances these ancient coral-reefs were covered by deposits composed in part of finely comminuted matter, probably derived from the remains of corals and other marine animals, but containing also appreciable quantities of land-derived mud. When those impure limestones were formed no corals lived nor as a rule are other fossils to be seen in such portions of the rocks. Again the conditions varied and corals reappeared and continued to flourish for a longer or shorter period, until another change unfavorable to their growth occurred; and in this manner several alternating bands of limestone, some crowded with fossils and others barren of the records of life, came into existence.

In some instances the Niagara limestone, as in the southern portion of the Garden Peninsula, is crowded with finely preserved fossils, consisting principally of corals and representing ancient coral reefs. Beautiful specimens of these relics are there strewn over the fields and in numerous instances have been gathered together and used in making stone fences. The reason for the abundance of these fossils at the surface is that owing to changes produced by the deposition of silica, after the rocks were consolidated and before being eroded, the original lime of the corals and other organisms was removed and replaced by silica, while the inclosing rock was not thus altered. By this process of silicification the fossils were rendered much less soluble than the rock containing them, and when exposed to the air and beaten upon by rains, were left when the more calcareous material surrounding them was removed. Resulting from this combination of conditions, we find today, strewn over the fields, wonderfully perfect and frequently exceedingly delicate and faithful representations of corals which lived many millions of years ago.

At certain localities as on Drummond Island, and in exposures of limestone in the hills about seven miles north of Hessel and Cedarville, the Niagara limestone is crowded with natural casts of the interiors of large brachiopod

shells of the genus *Pentamerus*. These may be readily recognized by the five divisions into which the casts are divided in the part where the two valves of the shell were hinged together. Other fossils are also abundant at many localities where the Niagara limestone is exposed, and make an attentive study of such outcrops both interesting and instructive. The fossil corals of the Niagara limestone and of other formations in Michigan, have been faithfully described and well illustrated by Carl Rominger, in Volume 3 of the reports of the Geological Survey of Michigan.

The Niagara limestone as will be more fully considered on a subsequent page, is in general and especially in its upper portion, harder and more massive than the formations with which it is immediately associated and hence has resisted erosion more efficiently than its neighboring terranes. It is also in general a magnesian limestone and in part a typical dolomite, and for this reason is less readily soluble than if composed of pure calcium carbonate; this also favors its preservation and together with its hardness, has enabled it to stand in relief while the surfaces of the less resistant adjacent formations have been lowered so as to form valleys.

A view of an artificial exposure of the lower portion of the Niagara limestone, in a quarry at Drummond, on the north shore of Drummond Island, is presented on Plate IV, which shows the nearly horizontal position occupied by the thin sheets of rock there present. A still more prominent feature, however, to be seen in the same picture, is the presence of two series of nearly vertical dividing planes or joints which cut the strata, and together with the bedding planes divide the rock into rudely rectangular blocks, thus greatly aiding the work of the quarryman. The joints so far as now exposed are narrow, nearly smooth sided fissures, such as one may suppose would be produced by sawing the rocks along two series of parallel lines at right-angles to each other; the saw being slightly inclined instead of vertical. The two series of master joints bear respectively N. 39° E. and N. 58° W.[1] or approximately at right angles; the joint planes although nearly vertical, are inclined to a horizontal plane as may be seen in the accompanying illustration.

Joints similiar to those just noted occur in many sedimentary rocks and in fact have a world wide distribution, but their mode of origin has not as yet been satisfactorily explained. As a modest contribution to the data, on which the desired explanation must be based, the following facts are here recorded: Near the Lake Survey Signal Station at Detour, nearly flat surfaces of limestone are divided by joints, and in their at present weathered condition resemble a rude pavement of flat stones; the joints having been widened to several inches owing to the solvent action of water on their walls. The major joints are here, as is usual in two series nearly at right angles to each other; the average of several measurements, shows that one series bears N. 39° E. and the other N. 53.8° W. In a neighboring exposure the respective bearings are, N. 51° E. and N. 48° W. In each case the nearly northwest joints are stronger and more prominent than the northeast series. The joint planes are nearly vertical but owing to the effects of weathering no satisfactory measurements of their inclination were obtained. In the Niagara limestone quarries near Marblehead, two systems of joints are again conspicuous, one bearing N. 66° E. and dipping southeast at an angle varying from 85 to 88°; and the other bearing N. 44° W. and dipping northeastward at an angle of about 80°. At Whitedale, two series of joints rendered con-

[1]These and other compass readings given in this report, have been corrected for secular magnetic variation, i. e. are referred to the geographic instead of the magnetic pole.

spicuous by weathering, were observed, one series bearing N. 24° E. and the other series N. 46° W.

The full significance of these and other measures of the position of joint planes is not now apparent, as they pertain to an unsolved problem, but are well worth noting. It will perhaps be found that the joints which are such a prominent feature of nearly all sedimentary rocks, have been produced by torsion generated in the earth's crust perhaps on account of variations in the rate of the earth's rotation, assisted as has been suggested, by earthquake shocks, and hence having an important bearing on profound questions concerning the relation of the earth to other planets, etc. There is yet another reason why joints should receive general recognition. They influence the manner in which rocks weather, and hence furnish a reason for many features in the shapes of cliffs and valley sides. By giving direction to streams, they also determine the major topographic features of many regions, such as hills and valleys, which have been produced by erosion.

The Lorraine and Utica Formation: The rocks to which this compound name is applied in recent publications of the Geological Survey of Michigan, are, as shown principally by their fossils, about the equivalent in age of the Hudson River shales of New York, and the Cincinnati limestone of Ohio, but in composition are intermediate between the two. They are not typical shales or representative limestones, but impure or argillaceous limestones. The significance of these differences in the rocks of the same age, deposited in the same ocean but at different localities, is that near the land in the case of the Paleozoic ocean as in the ocean at the present day, sand and mud were spread over the bottom while far from land calcareous deposits accumulated. In Northern Michigan, the rocks of the Lorraine and Utica formation were formed in a sea teeming with life, but where mud washed from land was being deposited in considerable abundance. The influence of these conditions is expressed by the organic remains still to be found in the rocks, which consist largely of brachiopod and molluscan shells and crustaceans, (trilobites) with but few and mostly small representatives of the corals. That is, the life was such as rejoiced in muddy bottoms, and did not include forms, like the corals, which thrive best in clear seas.

The rocks of the Lorraine and Utica formation occur in a belt from about two to five or six miles wide, concentric with and to the north of the similar curved belt occupied by the Niagara limestone, and extend from St. Marys River on the east to Big Bay de Noc on the west. Their distribution is shown on Plate III. The breadth of the outcrop of the formation just stated is not considered as accurate, since the region where it occurs is forested and occupied to a considerable extent by swamps, so that the nature of the underlying rocks and the precise boundaries of formations are difficult to ascertain. One of the chief features of interest concerning the Lorraine and Utica formations is its relative weakness in reference to erosion. Its softness and the thin bedding permit it to yield readily to mechanical agencies of erosion such as sand-laden streams, and glaciers in the basal portion of which stones are embedded, while at the same time the calcareous portions are subject to solution by surface or percolating waters. Mainly for these reasons the surface where these rocks are present has been eroded to a lower level as a rule, than the adjacent country where more resistant rocks occur and on account of its low relative position is now largely swampy. The Lorraine and Utica formation yields to denuding agencies more readily than the Niagara which overlies it or the Trenton which occurs beneath

it, and this finds expression, as will be considered more fully later, in the relief of the hard-rock surface beneath the glacial drift, etc. and especially in the presence of Green Bay at the west and Georgian Bay at the east, where the rocks of this formation have been excavated so as to form basins.

The best exposure of the Lorraine and Utica formation in the region especially considered in this report, is in the low lake-cliff on the east side of Little Bay de Noc opposite Escanaba. At this locality the nearly horizontal bedding of the deposit, its conspicuously argillaceous character, and its richness in organic remains are well illustrated. These same cliffs also show how the waves of the lake, by cutting away soft beds which occur beneath harder and more massive layers, lead to the production of precipitous and even overhanging escarpments.

The Trenton Limestone: A series of thin, mostly bluish, impure limestone beds occurring beneath the Lorraine and Utica formation in Northern Michigan is stated by Hall to be in reality compound and to represent several formations each of which has a thickness of many score feet in New York, but is termed the Trenton limestone of which it is mainly the representative. Its thickness in Northern Michigan as computed for its dip and breadth of outcrop, as well as from the records of drilled wells, is about 200 feet. It is stratigraphically next below the Lorraine and Utica formation, and owing to the basin-like structure of the rocks beneath the greater part of Michigan, comes to the surface in a curved belt concentric with the similar belts formed by the Niagara, etc., between St. Mary River on the east and the Menominee River on the west. This outcrop is mostly to the north of the region to which attention is invited in this report, but to the west of Green Bay, underlies the surface covering of glacial drift, etc., for a distance of twelve to over twenty miles westward from the bay shore. The formation is well exposed along the lower portion of Escanaba River, where it is quarried for building stone, and also appears at the mouth of Ford River, and at a number of other neighboring localities where it has been laid bare by erosion or trenched by streams.

To the north of the Trenton limestone in Northern Michigan, other layers of rock belonging to the Ordovician or Lower Silurian, and Cambrian periods are present, including as the lower member, the Lake Superior or Potsdam sandstone, which outcrops along the southern shore of Lake Superior from near Marquette eastward to St. Mary River, but concerning this important formation little need be said at this time.[1]

Geological Structure: By this term is meant the positions or attitude occupied by the layers of rock in the earth's crust. It is a well established fact that sheets of marine sediments of the general nature of those described above, are horizontal or essentially so, unless some force has been exerted on them and cause them to become inclined or folded. In Northern Michigan as already explained, the Paleozoic formations ranging in age from the Potsdam sandstone at the bottom, to the Monroe formation at the top, are inclined southward at low angles; the dip being southwest in the eastern portion of the country beneath which they occur, and changing gradually to southeast, when traced westward to the region bordering Green Bay. The succession of the rocks together with their gentle southward inclination is indicated in the following diagram, which represents the manner in which the edges of the various formations present from Point St. Ignace northward to Lake Superior, would appear if a great railroad cut for example, should be made along such a line and extended down to sea level.

[1] See Annual Report Geological Survey of Michigan for 1903, pp. 124–142.

As an attempt has been made to show in the following section, the edges of the more resistant beds stand in relief forming hills, while the less resistant rocks underlie depressions or valleys. The entire series of beds dips southward, the inclination being in general over forty feet to a mile. Similar sections in the Georgian Bay region would show a southwest, and if made in the Green Bay region a southeast dip. Without attempting to present all the evidence in this connection, the conclusion may be stated, as the result of a long series of observations carried on by various geologists, that Southern Michigan and a large region about it including the portion of Northern Michigan to the east of the longitude of Marquette, has a basin-like structure; the rocks in the central portion occuping a horizontal position, and those about the central area, being depressed and passing under it.

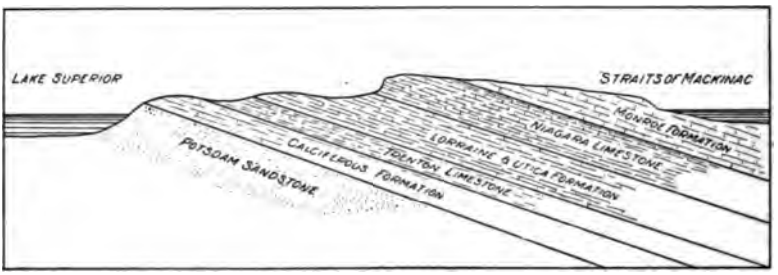

Fig. 4.—Ideal section showing succession of formations in Northern Michigan.

Owing to this basin-like structure the formations indicated in the above sketch section which in Northern Michigan have an inclination downward to the south, and disappear in succession as one crosses their edges in traveling from the north toward the south in the order of their age; reappear in part in Southern Michigan in reverse order and with a downward inclination to the north. That is, the originally horizontal beds in the Michigan region have been depressed in the central part of that area, so as to resemble a pile of shallow saucerlike dishes. The upper portion of the pile has been eroded to a generally plane surface, somewhat lower than the original surface of the central and last formed member of the pile. The concentric arrangement of the surface exposures or outcrops of the formations involved in the movements just described, is shown in part on the geological map forming Plate III.

The subsidence referred to went on during the time the various layers of sediments were being deposited, and was perhaps due in part to their weight, but was mainly produced, as is believed, by a more general cause, namely, contraction of the central mass of the earth beneath its cool and rigid crust. The downward movement while extending from the earlier portion of the Paleozoic era to the close of the Carboniferous period, was not necessarily continuous throughout this immense period of time, and there is evidence showing that upward movements occurred during certain stages, as near the middle of the Carboniferous period, when a land surface existed in the central part of the Southern Peninsula of Michigan, which was eroded and had gypsum deposited in its lake basins or lagoons, before the next succeeding sheet of marine deposits was laid down.

The deformation which produces the great structural or tectonic basin of Michigan, is one of the unique features in the geology of North America.

and one to which popular attention has seldom been directed. A proper understanding of its importance is necessary, however, in order to enable one to appreciate the significance of many facts concerning the geology of the hard rocks which have a direct bearing on matters of commercial importance, and in order also to learn the fundamental reason for the existence of some of the geographical features of the Great Lakes region. The Michigan tectonic basin is rudely circular and approximately 500 miles in diameter; its center being in the medial portion of the Southern Peninsula, near Midland. In this central region the amount to which the lowest rocks involved in the downward movement have been depressed below their original position, is as nearly as can now be judged, not less than five or six thousand feet. In many portions of the earth's crust, the rocks composing it have been upheaved into great domes from which mountains have been carved, but it is exceptional to find an extensive region where the opposite result or the production of a reversed dome of vast dimensions, has been reached with but little secondary disturbance, and not followed by an upward movement.

In the Michigan region the great subsidence mentioned went on during a large portion of, if not the entire, Paleozoic era; the oldest sediments known to have been involved being the Cambrian, and the youngest the Coal Measures. The subsidence permitted of the deposition of sheet after sheet of marine sediments, within generally narrower and narrower limits as the pile increased in thickness, until the coal-bearing rocks which occupy the center of the basin were deposited. This great subsidence occurred with but little secondary folding or crumpling. It is probable, however, that irregularities of the nature of up and down folds, radiating from the central portion of the depressed region towards its periphery are present, but are as yet undiscovered. This conclusion is suggested by the fact that a series of horizontal beds if depressed in its central part must be either stretched to admit of the change of shape, or be plicated in radial folds. Evidence of plication in beds that have been elevated into domes is well known, but a flow of the material of which rocks are composed so as to admit of an adjustment to a new position during such movements is much more difficult to detect. Probably each of these changes were brought about in the rocks of the Michigan region and evidence of radial folding should be looked for, since it is a matter of great economic importance in reference to the storage of gas and oil.[1]

The significance of the general structure of the Michigan tectonic or structural basin in reference to the geology of the part of the State under immediate consideration, is, that the hard rocks there present are included in the outer portion of the series of concentric belts formed by the coming to the surface of the deeper of the basinshaped formations which underly Southern Michigan. The rims of the lower members of the pile of geological saucers, so to speak, form segments of concentric belts, concave southward, which sweep in remarkably regular curves from St. Mary's River westward well into Wisconsin. On the west this series of curved belts meets a region of crystalline rocks exposed owing to the erosion of a region of upheavel, but on the east the influence of the Michigan tectonic basin is apparent throughout the western part of Ontario.

1 In this connection it may be suggested that wells drilled in Southern Michigan with the hope of obtaining gas or oil, would have the best chance of success if distributed about the borders of that Peninsula where radial anticlinals pitching toward the central part of the basin, may be expected to approach the surface and to afford the requisite conditions for the storage of oil and gas. Where these localities are, if they exist, has yet to be discovered. Information in this connection, however, may be found in the reports of the Geological Survey of Michigan for 1901, and 1903.

Topography of the hard-rock surface. The attention of the reader has already been directed to the fact that the geology of the region bordering lakes Huron and Michigan on the north, has two leading and conspicuously different divisions; one relating to the stratified sheets of marine sediments, now for the most part hardened into compact rock, mostly limestone; and the other dealing with the superficial covering of loose and in large part unconsolidated debris, largely sandy and stony clay, resting on the surface of the older series of formations. In the language of geologists, the younger formation rests unconformably on the older series of formations, and between the two periods of accumulation there was a vast time interval. This interval, lost so far as the geological deposits of Michigan were concerned, extends from near the close of the Carboniferous period to the Glacial epoch. During much of this interval the region occupied by Michigan was a land area, and subjected to erosion. The records of the changes that occurred are therefore, to be looked for on the surfaces of the older rocks, and as is to be expected, must be mainly of the nature of hills and valleys produced by erosion. The shapes and other characteristics imparted to the outcrops of the older rocks thus become matters of great interest, since such features take the place of the more common class of geological evidence furnished by sedimentary and other deposits. The relief of the hard rock surface is also of interest in connection with the study of the superficial deposits resting on it, for the reason that it enables one to measure the thickness and ascertain other features of the superficial accumulations.

To ascertain the characteristics of a rock surface buried beneath subsequent deposits, is in most cases a difficult task, and one that is usually accomplished principally by obtaining the records of wells, mines, etc., which pass through the material beneath which it is concealed. In Northern Michigan, this task is less difficult than in most of the formerly glacier-covered portions of the United States, for the reason that the glacial and other deposits occupying the surface are everywhere comparatively thin, but as much of the country is forest and swamp-covered, the work of assembling the necessary data is tedious. Over large areas, wells and other excavations are wanting and natural conditions such as rock outcrops, etc., are alone available.

In spite of the meagerness of the facts in hand it is evident that in the part of Michigan under consideration, the hard rock topography does not differ materially from the relief of the surface of the superficial material resting on it. This conclusion will no doubt be a surprise to persons who have studied other portions of the formerly glaciated region of the United States, where as a rule, the superficial accumulations are deep enough to effectively conceal the relief of the surfaces of hard rock on which they repose. Throughout Northern Michigan, however, the glacial drift is so thin and forms such a uniform blanket, that it has essentially the same inequalities of surface as the floor on which it rests. It is only locally that the surface deposits have a topography peculiar to themselves which thoroughly masks the relief of the hard rock surface beneath.

The major features in the present relief of the region to the north of lakes Huron and Michigan, can be correlated with the varying degree of resistance to erosion of the Paleozoic formations there present. Here as elsewhere, the resistant rocks stand in relief, forming hills and ridges, while the less resistant rocks have been eroded so as to give origin to valleys. The basins of lakes Huron and Michigan as was first pointed out I believe, by Hall and Whittlesey, are situated where the Monroe formation (the Helderberg and

Onondaga salt group of Hall) which is less resistant both to the mechanical and to the chemical agencies of erosion than the formations above and below it, would be present, if it had not to a large extent been removed. Remembering the concentric arrangement of the belts of rocks formed by the edges of the various layers in the Michigan tectonic basin, it follows that if the basins of lakes Huron and Michigan have been excavated in the Monroe formation they should have the position which would have been occupied by that formation if it had not been excavated. By referring to a geological map of the Great Lakes region (Plate III) this will be seen to be essentially true.

As stated by James Hall, the basin of "Lake Michigan has been, to a great extent, excavated from the Onondaga salt group and the upper Helderberg series" [the Monroe and Dundee formations] "while the Niagara limestone, being harder and more indestructible, forms its western border from one extremity to the other. From the breadth of the country over which we find vestiges of the Onondaga salt group and the upper Helderberg series in the northern parts of lakes Huron and Michigan we are warranted in the conclusion that at least two-thirds of the latter lake in a direction conforming to its trend, has been excavated in these limestones." A similar conclusion was also reached by Whittlesey, in reference to Lake Huron; "The Niagara limestone there forms a barrier occasionally broken through, extending along its northern shore embracing Cabot's Head, and the Grand Manitoulin islands. It dips southerly, so as to leave the Onondaga salt group and the upper Helderberg series to the south; and the area once occupied by them is now covered by the waters of this lake."

The eastern and northern shore of Lake Huron from Goderich northward, and the entire northern and western shore of Lake Michigan, are composed of Niagara limestone which dips toward the water bodies it margins. The only exception to the continuity of the Niagara in the nearly semicircular coast line, over 600 miles long, extending from Goderich to Chicago, is where the rocks of the Monroe formation appear in the St. Ignace Peninsula. This exception is significant and a reason for it is suggested on page 57.

The fact that the sheet of Niagara limestone dips toward the lakes it margins, as just mentioned, at once suggests a reason for the general lowness of these shores, and their lack of bold or picturesque scenery. At many localities the gently-sloping surface of the limestone passes beneath the water at the lake margin without noticeable change due to abrasion by the waves. At other localities and particularly at the ends of capes, the waves and currents have cut small lake-cliffs, but those features are seldom conspicuous. Bluffs are present at certain localities, however, about the portions of lake shores just referred to, but so far as I am aware, they owe their prominence to lake-cliffs cut in glacial drift and similar material belonging to the surface blanket of rock debris, or to the presence of sand that has been drifted into dunes by the wind.

From the brief outline of the conditions about the outer shores, as they may be termed, of lakes Huron and Michigan, that is, the shores farthest removed from the center of the Michigan tectonic basin, it will be seen that not only do the basins of these lakes owe their existence and position to the structures and differences in resistance to erosion of the underlying rocks, but many of the scenic features of their present borders are controlled by these same conditions.

1. Foster, J. W. and J. D. Whitney, Report on the geology of the Lake Superior Land District, 1851, p. 176.

As the Niagara limestone dips toward the two of the Great Lakes which it borders respectively, and gives them low shores, it will be inferred no doubt, that the outer margin of the outcrop of the same bed of resistant rock should rise high in the air and form a bold ridge, or a series of prominent hills. This deduction is sustained in part by the present relief.

While the Lake Michigan shore of the Garden Peninsula is low and sandy, the opposite shore facing Big Bay de Noc, is notably bold, and presents several headlands which are prominent and mildly picturesque. The most conspicuous of these headlands known as Burnt Bluff, rises precipitously to a height of 225 feet above Big Bay de Noc, and is composed of Niagara limestone which dips gently toward the southeast. The prominence of Burnt Bluff and in general the boldness of the southeast shore of Big Bay de Noc inclusive of Middle Bluff, Garden Bluff, etc., is due directly to the structure of the rocks, and especially to the greater resistance offered to the agencies or erosion, by the Niagara limestone than by the weaker Lorraine and Utica formation on which it rests and which comes to the surface in the next concentric belt outward from the Niagara belt.

The greater prominence of the outward-facing or northern border of the Niagara limestone over its inner or southern border, is manifest also in the hills situated six to eight miles north of Manistique, and again in the hills which rise to the north of Hessel and Cederville. Whether a northward facing escarpment is present or not, between these two localities is unknown. An examination of such maps of this region as are available, fail to show that the Niagara limestone has controlled the direction of the present streams. This fact suggests that the maps are not sufficiently exact, to bring out such a relation if it exists, or that the erosion particularly by glaciers, together with the glacial deposits left on the country, have modified the topography to such an extent that the influence of the hard rocks on the direction the streams follow is no longer the controlling condition. On the northern border of Drummond Island, and generally about the southwest shore of Georgian Bay, the land is bolder and more picturesque than the neighboring shores of Lake Huron, for the same reason that the Bay de Noc border of the Garden Peninsula is higher and more precipitous than its Lake Michigan border.

The belt of rocks next to the outer margin of the curved belt underlain by the Niagara limestone, namely the Lorraine and Utica formation it will be remembered, is composed of earthy limestone in thin layers, and is much less resistant to the agencies of erosion than the formations adjacent to it. This belt of weak rocks should therefore have been eroded away more effectually than the adjacent beds, and given origin to valleys and lake basins. In fulfillment of this prediction we have Green Bay and its connecting bays, in the northwest portion of the Michigan tectonic basin, opening to Lake Michigan through narrow channels in the Niagara limestone; and Georgian Bay and North Channel in the northeast portion of the same great basin, opening to Lake Huron by means of narrow channels through the intervening land, composed of the same sheets of limestone, namely the Niagara, which shuts in Green Bay, etc. This symmetrical arrangement of Green and Georgian bays, with reference to the structure of the underlying rocks, is of the same nature as the relation of the basins of lakes Huron and Michigan to the same series of conditions, and increases one's confidence in the conclusions reached by Hall, Whittlesey and others, in reference to the basins of the Great Lakes being due largely to erosion. Now, two chief agencies of erosion, namely streams and glaciers, have been in operation in the Great Lakes region,

and the question arises, which of the two is to be held chiefly responsible for the production of the basins the Great Lakes occupy. This question has been much discussed, but is still not answered to the satisfaction of all persons interested in it. It may perhaps not be digressing too far to suggest, that the intimate relation between the basins of lakes Huron and Michigan, and of Green and Georgian bays, respectively, to the weak formations on which they are located, suggests the long continued action of streams previous to the Glacial epoch, rather than the work of ice. Strengthening this view is the fact, as will be stated more fully later, that the main direction of ice movement as recorded by striæ, etc., on the Garden Peninsula, was athwart the longer axis of Big Bay de Noc and on Drummond Island was again nearly at right angles to the adjacent portion of the longer axis of Lake Huron. There were other glacial movements in each of these regions, however, and how much the flow of the ice favored the deepening of the lake or bay basins is difficult to determine. There is another series of facts of interest in this connection which needs to be discussed, that is the deposits of remarkable thickness, in places and over large areas amounting to between three and five hundred feet, which the former glaciers left in the region south of the Straits of Mackinaw and extending to central Ohio and Indiana. It thus seems probable that the glaciers did more toward the filling of the basins of lakes Huron and Michigan than they did in the way of deepening them.

Beside the basins now occupied by the waters of the Great Lakes a brief account of which has just been presented, there are other features in the hard-rock topography which have a bearing on the question as to the depth of glacial erosion. The valleys now occupied by the principal streams which enter Green Bay and the northern portion of Lake Michigan, such as the Manistee, Escanaba, Rapid and White Fish, and Manistique rivers, are older than the glacial epoch and show something of the relief of the surface before it was modified by glacial action. This conclusion is based on the size of these valleys in reference to the volume of the streams now occupying them, and the fact that above the reach of the present streams, the valley bottoms are covered with glacially deposited debris and their floor in places scored with glacial striæ. It is apparent that the valleys are not only of pre-glacial origin and were modified to only a slight degree by the glaciers which subsequently occupied them, but that the present streams have been enabled to do but little rock cutting since their present cycle of work began. The conclusion which one has forced upon him while travelling over the country drained by the river just named, and the same is true also of the region extending east from Manistique River to Drummond Island, is that the relief of the hard-rock surface beneath the superficial blanket of glacial and other debris, controls the present topography. That is, the depth of the glacial deposits, etc. is usually only locally sufficient to mask the relief of the underlying hard-rocks and give a new topography to the land. More than this, as seems to be generally true, the changes produced in the hard-rock topography by the glaciers which have passed over it, are of minor importance. The present relief, is therefore, with the exception of details, such as the long period of subaerial erosion which preceded the Glacial epoch impressed upon the surface of the land. This broad conclusion will no doubt be controverted by some students of the changes glaciers produce and is admittedly based on less evidence than I desire, but I think will sustain the test of future and more extended investigation.

Additional and conspicuously obvious facts bearing on the above mentioned

conclusion, are furnished by Mackinac Island and Burnt Bluff. Mackinac Island rises 317 feet above Lake Huron, and the surrounding water is in general from 100 to 200 feet deep. Burnt Bluff has a height of 225 feet above Lake Michigan, and the adjacent water is from ten to fifty feet deep. Each of these bold eminences stood in the paths of the glaciers which successively covered the region where they are situated but were not removed. Mackinac is precipitous on its southern border and declines less abruptly but still with steep slopes toward the north, and may perhaps be claimed to exhibit in its general contour the effects of ice abrasion on its northern side, and of "ice-plucking" on its steeper southern face. In the case of Burnt Bluff, however, the topographic relations are reversed in reference to ice movement as the precipitous side of the bluff faces the northwest, which as shown by striæ on neighboring rock-surfaces, is the direction from which came the last of the former ice sheets which covered the region. Both Mackinac Island and Burnt Bluff have till on their summits, showing that they have been completely buried beneath glaciers. Burnt Bluff reveals no evidence of ice abrasion in its general shape, or in the contour of its summit. It might perhaps be surmised that its present cliffs which face the direction from which came the glaciers that passed over and around it, are due to wave action since the last ice sheet melted. This is not true however, since the shore marks of lakes Algonquin and Nipissing are present on the face of the cliff and show that but little undermining has been done by the present lake. The effect of glaciers in rounding rock escarpments against which they flow, is here as conspicuous by its absence as in other localities it is rendered evident by the topographic forms produced. Both Mackinac Island and Burnt Bluff stand as conspicuous monuments to the fact that great glaciers even when their attacks are several times repeated, are under certain but as not yet well understood conditions, unable to seriously abrade, much less remove rock bosses and prominent peaks which stand in their paths.

Mackinac Island: An exceptional feature not only in the topography of the part of Michigan especially considered in this report, but unique in comparison with the relief of the entire Great Lakes region, is furnished by Mackinac Island and to a less conspicuous degree by the hills about St. Ignace. Mackinac Island, as is well known, is situated in the extreme northwest portion of Lake Huron. It is about nine miles in circumference, contains 2,221 acres and is the highest land in that region, within a radius of probably more than a hundred miles. Considering the topography of the hard-rocks of the island beneath the surface covering of glacial drift, etc., its prominence becomes still more significant. The height of the summit of the island above the adjacent lake bottom as stated above, is not less than 500 feet. Its southern border is precipitous and in places forms cliffs a hundred feet or more high, near the bases of which the water is in places about 100 feet deep.

The precipitous southern border of the island and including also the similar cliffs on its eastern and western shores have been accounted for by Hall as resulting from the presence beneath the massive Helderberg limestone of weaker limestone and gypsum of the Onondaga salt group. No doubt this explanation is the true one so far as the precipitous nature of the cliffs in question is concerned, but a greater problem, namely how did it happen that the isolated mass of rock forming Mackinac Island came to be left in bold relief while nearly all other portions of the outcrop of the formation

to which it belongs has been eroded so as to form deep depressions, namely, as already explained, the basins now occupied by lakes Huron and Michigan.

Limestone is as a rule a weak rock in reference to its ability to resist the attacks of the agents of either mechanical or chemical denudation. Very commonly also, limestone areas are depressed in reference to the region about them for the reason that in general limestone is more easily eroded than most other common rock. This is due principally to the readiness with which limestone—and dolomite also—is dissolved in percolating water, and the small per cent. of insoluble matter which it usually contains.

Mackinac Island, standing as it does in bold relief presents a conspicuous exception to the normal topography of regions underlain by rocks similar to those of which it is composed and its preservation must evidently be due to some exceptional condition which influenced erosion. The explanation which suggests itself in this connection is that the great sheet of rocks of the Monroe formation which comes to the surface in the region now occupied by lakes Huron and Michigan, was cavernous at the localitiy where Mackinac Island is situated, and that during the long period of subaerial exposure and stream erosion preceding the Glacial epoch, the drainage at that locality was subterranean and surface streams were locally absent. That is, the rain water instead of being gathered into rills and brooks at the surface and eroding, descended into the openings in the limestone, which was partially removed in solution but at a less rate than the surface was lowered when the waters formed streams in the ordinary manner. This explanation is in harmony with the fact that the rocks of Mackinac Island and of the St. Ignace Peninsula, are brecciated as already explained, and the suggestion furnished by Arch Rock, that caverns are present. Under this explanation, Mackinac Island and the less conspicuous hills about St. Ignace, are to be considered as remnants left by erosion or "monadnocks" as similar residual hills have been termed; and owe their preservation to the influence of subterranean drainage

The instances just described do not stand alone as examples of rock masses spared by erosion because of their broken and cavernous condition, but are of special interest for the reason that the influence of subterranean drainage on topography has received but little attention.[1]

SURFACE GEOLOGY.

As I have already attempted to indicate, much of the geological history of Northern Michigan is recorded in the topography of the hard-rock surface. The older portion of this record pertaining to the time previous to the Glacial epoch, is much defaced and difficult to read, and as yet has received but little attention. Inscribed on the same surface, or resting upon it, however, are much fresher records the significance of which is clear. I refer to the striæ and other markings and the deposits of debris, left by the glaciers which passed over the land in times geologically modern. As is well known, ice sheets of the type of continental glaciers, such as cover the greater part of Greenland at the present day, formerly moved southward over Michigan

[1] A brief essay in this connection may be found in Science, Vol. XXI, 1905, p. 30–32.

in common with the vast area embracing about one-half of the continent of which it forms a part, and extending as far south as the Ohio river and Kansas. As is also well known, there were several distinct advances and recessions of the ice, or glacial and inter-glacial stages. In order to indicate at least in a general way the position in this complex history, to be assigned the glacial records of Northern Michigan, the following schedule of the subdivisions of the Glacial deposits in North America, as now known, is here introduced; the deposits made during the earliest known ice-advance being at the bottom of the list.

GLACIAL OR PLEISTOCENE SERIES..	9. Wisconsin till-sheet. (earlier and later.)
	8. Interglacial deposits. (Peoria beds).
	7. Iowan till-sheet.
	6. Interglacial deposits (Sangamon beds.)
	5. Illinoian till-sheet.
	4. Interglacial deposits (Buchanan beds.)
	3. Kansan till-sheet.
	2. Interglacial deposits (Aftonian beds.)
	1. Pre-Kansan (Albertan) till-sheet.

These subdivisions of the glacial records have been made out principally for the deposits which the glaciers left in the region to the south of the portion of Michigan especially considered in this report, and we look with interest for similar evidence in more northern regions with the hope of discovering in particular, how far north the ice front retreated during the several interglacial stages. Some evidence in reference to a far northward extension of the deposits made during what seems to have been the Sangamon interglacial stage, has recently been obtained by Frank Leverett as will be stated later, but in general the glacial records in north Michigan are referred to the Wisconsin stage of ice advance.

The records pertaining to the Glacial epoch in the region under consideration, are principally striæ and other markings on the surfaces of the hard-rocks; deposits such as till or stony-clay in widely extended sheets or fashioned into smooth, oval hills termed drumlins; boulders strewn over the land; ridges of sand and gravel made by streams beneath the glaciers and known as eskers; and sand and gravel plains due to the deposition of debris swept southward from the glaciers by the streams fed by their melting.

EVIDENCES OF ICE ABRASION.

Striæ: Both existing and ancient glaciers, under certain conditions,as has been abundantly proven, in moving over their beds plane away the rocks on which they rest and frequently polish and striate them as well as bring about other changes by abrasion which may be easily recognized. These results are produced especially when the ice is lightly charged with sand and stones set in its basal portion. If the supply of debris thus held becomes sufficiently abundant the movement of the ice is checked, the clearer part above passing over the more thoroughly debris-charged portion below, and the hard-rock surface beneath a glacier is protected instead of being abraded.

Smoothed and striated rock surfaces are common in North Michigan wherever the hard-rock has recently been brought to view by the removal of a protection covering such as sand and clay. On the rock surfaces that

have been exposed to the air for a considerable but indefinite time, weathering has in most instances removed all evidences of ice abrasion which may formerly have been present. The most promising localities to look for glacial striæ and associated inscriptions, are where excavations have recently been made which lay bare the surface of the hard-rock beneath the deposits of clay or other protecting material. The localities where glacial striæ has been observed in the region represented on the map forming Plate XVI, are indicated on the map by arrows. Where the dircetion in which the ice moved is definitely known the arrows are barbed; when two directions of ice movement are present the weaker and in all instances as seems evident, the older series is indicated by a broken arrow. The arrows without barbs have been drawn from observations made by E. Desor, in 1850; the remainder are based on notes made by myself.

It is apparent from an examination of the map just referred to, that the directions of ice movement there recorded, are discordant in a conspicuous manner. The only general conclusion to be derived from the striæ is that the glaciers which made them flowed from a northerly to a southerly region, but the variations embrace a range from north to south and west to east. Certain of the striæ are at right angles to the directions of neighboring striæ, and in one case, namely at the mouth of Ford River, two series of glacial grooves on the same surface are at right angles one to the other.

The chief reason for the discrepancies just indicated seems to be that the ice sheets which made the striæ did not flow uniformly in one direction but in currents which took various directions during different stages in their advance or retreat, and also that the markings even in a single locality, were not all made at one time.

As has been well determined, the ancient glaciers which covered the Michigan region advanced more in certain portions of their southern margins than in other portions, and became strongly lobate, and also that the ice in each lobe spread laterally in addition to advancing toward its end. As the ice front receded northward, the lobes about its margin also receded and therefore at any specific locality, a change in the direction of the striæ made on the rocks at different times would vary in direction. As has been shown especially by T. C. Chamberlin, the ice over the Michigan region during its last retreat formed conspicuous lobes in the basins of Green Bay, Lake Michigan, etc., but so far as is apparent, the striæ platted on the accompanying map do not have a definite relation to the glacial lobes thus far recognized.

The data in hand although confessedly meager, certainly suggest that currents with diverse directions, were present in the basal portion of the glacier which made the striæ referred to; their direction being determined by local variations in the relief of the underlying rock, or due to the greater abundance of debris in the lower part of the ice at one locality than at another—the presence of debris tending to retard the motion of the ice containing it.

Observations favoring the idea that a broad ice sheet does not flow in a single uniform direction, but in currents which have different rates of motion and different courses, have been made on the Malaspina glacier, Alaska.[1] On that glacier a conspicuous compound moraine supplied by the great tributary ice stream named the Seward glacier, crosses its surface from the north and on meeting the stagnant ice near its southern margin, divides and

[1] Russell, Israel C. "Second expedition to Mount St. Elias, in 1891," in U. S. Geological Survey, 13th Annual Report, Part II, Plate IV.

forms a series of concentric bands, several miles in diameter, on either hand. On looking down on the glacier from neighboring mountains, the medial moraine referred to is seen to divide at its distal end in much the same manner that the broken end of a celery stalk usually divides and curls upon itself. Evidently very complex currents must be present in the glacier to produce such conspicuous changes in the direction of its surface moraines, and similar currents may be expected to be characteristic of the flow of other widely extended ice sheets.

Another reason which may be appealed to in attempting to account for the observed diversity in direction of glacial striæ along the northern borders of lakes Huron and Michigan, is that such markings made during one ice advance might be covered by till or other deposits, and thus preserved during a subsequent stage of glaciation. Or, what is essentially the same in principle, a glacier may abrade the rocks over which it flows, during one portion of its existence, and deposit subglacial till upon them during another stage; and perhaps still later re-erode its own deposits and continue the work of rock abrasion in a different direction. I suspect that some such combination of conditions is mainly responsible for the conspicuous diversity in the direction of the ice movements referred to above.

It is instructive to note in the above connection that the region under consideration, is situated to the north of a deeply moraine and till covered region and south of a still greater region from which the former glaciers removed nearly all superficial material and abraded the rock surface thus exposed. In the belt of country between the region where glacial abrasion was in excess of deposition and the region where deposition was conspicuously great, alternate abrasion and deposition under the control of fluctuating conditions may well have been the rule.

Instances where two series of glacial striæ are present on the same rock surface, as at a quarry near the mouth of Ford River, and again about one mile north of Hessel (and many similar instances are known elsewhere) are difficult to explain on the supposition that the abrasive action of the ice was continuous at each locality, or, as has been assumed in reference to such instances, that each set of striæ is a record of a separate ice advance, without the intervention of a protecting layer. One suggestive fact in connection with rock surfaces which are inscribed with two sets of striæ is, that the abrasion which produced the second series of records, was not intense. The striæ in the instances referred to above, are only a fraction of an inch deep, and the older series would have been completely removed during the production of the younger series if more than an inch of the rock surface had been worn away at the time the ice last rested upon it. It is not correct to assume, however, from this fact taken singly, that glacial abrasion is but slight, since a deep protecting sheet of till might have been laid down on the inscribed rock surface after the first series of markings was made and efficiently sheltered it from abrasion during a part of a later stage in the advance of the ice. It thus appears that striæ and associated glacial markings while affording definite and important evidence of ice work and recording faithfully the direction of glacier motion for a given locality, do not furnish a sure basis for generalization in reference to different ice advances, or separate stages of the glacial epoch, unless similar evidence is recorded at a large number of localities, and the conclusion reached is sustained by other testimony.

Two sets of glacial striæ on the same rock surface have in some instances and perhaps truthfully, been assumed to furnish evidence of two stages of

the Glacial epoch, separated by an interglacial stage of ice retreat. To permit of the making of such a double record it is self evident that the first series of records must have been well covered during the intervening stage of deglaciation, for if exposed to the air for even a few score years they would have been removed or seriously defaced by weathering; and also, that during the second ice advance, the period of abrasion must have been brief, or the intensity with which the sand-and-stone-charged ice scored and scratched the rock surface exceedingly slight. Otherwise the earlier record,—in many observed instances consisting of shallow grooves and striæ, none of them when first formed as may be reasonably inferred, being over an inch deep,—would have been completely removed. When two series of glacial striæ are present on the same rock surface, the inference seems warrantable that the second series were made during a brief period of time or else that the bottom of the passing glacier was nearly free of tools with which to work.

The best general principle to bear in mind, while seeking to interpret the meaning of glaciated surfaces, seems to be that glaciers are capable both of abrading and of making deposits on the surfaces over which they pass, and that these two processes may alternate, the one with the other at a given locality; and also that broad ice sheets do not flow uniformly in one direction but have at least basal currents which are more or less flexible, although for a considerable area following the same general course.

Knobs and Trains: On the surfaces of the limestones and dolomites crossed by grooves and striæ as noted above, there are several other kinds of markings which are significant and have their special stories to tell in reference to the manner in which glaciers abrade rock surfaces. The nature of the markings referred to has been critically described and their meanings discussed by T. C. Chamberlin[1] and while I have nothing new to contribute to this branch of glacial geology, certain observations are at least of local interest.

An approximately level surface composed of rock of uniform texture and hardness, when worn by the passage over it of a glacier charged with fine debris, will be worn smooth and perhaps highly polished, but on the polished surface straight parallel striæ produced by individual sand grains are usually visible. Departing from this normal result as it may be termed, modifications are produced owing (1) to variations in the relief of the rock surface, (2) variations in the texture of the rock, and especially the presence of silicified fossils, chert nodules, etc., harder than the matrix holding them, and (3) variations in the size and character of the foreign bodies embedded in the moving ice which serve as abrading tools.

The influence of inequalities of surface, need not be considered at this time, since in the region about the northern shores of lakes Huron and Michigan the rocks which have been glaciated are in general nearly flat, and no conspicuous evidence of the rounding of prominences or the broadening of depressions was observed. On the other hand, what appear to be conspicuous exceptions to the rule that glaciers tend to remove prominent elevations on the surfaces over which they pass, or to impart to such eminences rounded and flowing outlines, are furnished by the rocks forming Mackinac Island, and the hills about St. Ignace; as well as by several equally conspicuous elevations on the west shore of Garden Peninsula, the most prominent of which is Burnt Bluff. The hills referred to, as already explained, stood

[1] Rock-scorings of the great ice invasion, in U. S. Geological Survey, 7th Annual Report, Washington, 1888, pp. 147–248.

in the paths of the former glaciers and were completely over ridden by them, but give no suggestion in their forms of having been abraded. These conspicuously exceptional features of a glaciated region will be considered more fully on a later page; the immediate subject in hand being the characteristics of ice-abraded rock surfaces.

The influences of variations in the texture of rocks on the characteristics of ice-abraded surfaces, is well shown at several of the localities indicated on the map forming Plate XVI, where striæ are recorded, and particularly on Drummond Island, the locality north of Hessel, near Orville, and at Marblehead. At each of these localities and less conspicuously at other places where striated rock surfaces were seen, the limestone or dolomite, contains silicified fossils, which are harder than the rock about them. In numerous instances where such bodies are embedded in a glaciated surface, there are grooves about their borders on the side from which the ice came; these grooves usually a fraction of an inch in depth and in width, extend along the lateral margins of the obstructions, and becoming less deep die out at a distance of an inch or so on what may be termed their lee border in reference to the direction the ice flowed over and about them. When these grooves are present there is also a tapering ridge on the lee side of the obstruction and at its proximate end having the same height above the adjacent surface, which tapers to a point in the direction the ice moved. In many instances, however, the tapering ridge on the lee of a silicified shell, is present, but a frontal groove with its decreasing laterals is absent.

The grooves and ridges just described, are of special interest as they show the direction in which the ice moved which produced them. The grooves occur on the side of the obstructions from which the ice came and passing about them, die out in the direction in which the ice moved; while the tapering, cone-like elevations, are on the lee side of the obstructions and point in the direction the ice left them as it flowed. While the grooves and striæ that glaciers charged with debris make on rock surface, do not in themselves show in which direction the abrading tool moved which engraved them whether, for example, from north to south or south to north, the grooves and trains just described answer this question with great precision. There are other markings, also, as will be noted below, which furnish similar testimony.

The grooves and ridges just referred to, are also instructive in reference to the evidence they furnish concerning the physical condition of the ice which shaped them. The grooves show that a downward direction or eddy-like movement was given to the ice when it met an obstruction, similar to the eddy on the upstream side of a stone in a stream, which enabled the ice to scoop out a depression in the rock surface; but the tapering train on the lee side of an obstruction is equally positive evidence that the ice did not plunge over the elevation in its path as flowing water would have done, so as to scoop out a depression on its down stream side, but on the contrary, there was a relief of pressure in such situations and less abrasion than on the adjacent surface. In other words, an obstruction met by the ice formed a groove in its bottom which slowly collapsed. An exceedingly delicate adjustment of the ice between a condition of fluidity and a condition of rigidity is thus indicated; the ice being in such state that it could flow about the obstruction and be deflected downward so as to grind out a groove, and at the same time sufficiently rigid to be itself grooved by the obstruction over which it passed, and kept from abrading the

rock under its lee. The knobs with grooves and striæ seem to show that ice under heavy pressure behaves like a viscous but almost fluid body, but variations in the results produced on abraded surfaces—such as the absence of the frontal grooves about obstacles in many instances and the presence of striæ and deep grooves which imply a firmly held tool—are equally eloquent in proclaiming the rigidity of the ice which was concerned in their production. These diverse conclusions seem to show that the ice in the basal portion of glaciers is at times viscous and almost fluid-like in its mobility, and at other times behaves as a decidedly rigid solid. Two variations in the controlling condition may reasonably be surmised to account for these contrasts in results—first differences in pressure, and second, variation in the percentage and character of the foreign material, such as sand, gravel, etc., present in the ice.

Variations in pressure while tending to vary the degree of plasticity of ice,—if the pressure were sufficient it would cause the ice to melt at the temperature normally present, and thus become a fluid—can scarcely be claimed as the controlling condition which produced the differences in results referred to, which in one area record the passage of a highly viscous body, and on a neighboring surface, give evidence of the passage of a decidedly rigid body. Indeed, both of these contrasted conditions are frequently recorded on the same surface only a few square feet in area. At the bottom of a glacier several hundred and possibly a few thousand feet thick variations in pressure from place to place or variations in short spaces of time at the same locality, cannot reasonably be assumed to be such as to produce the differences in the grooved and ridged rock surfaces to which attention has been directed.

While pressure on ice tends to make it behave as a plastic body—the greater the pressure up to the limit of elasticity, if not to the point of melting—the greater the plasticity—debris added to the ice acts in the other direction and tends to reduce plasticity, and if present in sufficient amount would cause the ice to remain stagnant under conditions of pressure which otherwise would cause appreciable flowage. Differences in adjustment therefore between pressure and per cent. of contained debris may be taken as the immediate control which determines whether the ice at any locality in a glacier will behave as a rigid or a plastic body. This conclusion requires, to be qualified, however, as not only the per cent of superficial pressure present material such as sand and gravel—but the degree of comminution exerts an influence as does also—not to a less extent perhaps—the uniformity or heterogeneity of grain. For example a given per cent of fine sand—a mere film of a given mass of ice would exert a different influence on its flow under pressure than if the same per cent of coarse was in the form of gravel or large boulders.

[illegible]

limestone, and the trains on the lee sides of such elevations seem to have been produced. If the percentage of foreign material present in the ice should be increased, it would make the mixture more and more rigid, the pressure remaining the same, and may reasonably be assumed to impart to the ice such a consistency that it would hold firmly to sand grain, or larger rock fragments, and carry them along so as to striate and groove the rocks over which they were drawn. Under this latter condition the small grooves and trains, considered above would not be produced, but larger features of a similar nature might result. Observations are seemingly in harmony with these deductions, since frontal grooves and lee-trains are absent from deeply striated rock surfaces, but features of a similar character as rock bosses, with or without trains of debris on their lee, are features in the landscape of many glaciated countries. These considerations invite a discussion of the entire field of glacial abrasion, glacial flow, etc., but this would lead too far afield.

In connection with the facts concerning glaciated rock-surface referred to above, I desire to put on record one suggestive observation which may be of interest to the reader.

On a finely polished limestone surface exposed at the bottom of a well, about 25 feet deep, dug in reddish, bouldery till, near Orville, there are many well-formed frontal grooves and leeward-tapering trains, associated with fossil shells embedded in the rocks and partially exposed to view by glacial abrasion. One fragment of a shell, nearly an entire valve of a brachiopod, about the size and thickness of one's thumb nail, was emplanted vertically in the rock at right angles to the direction of the former ice movement. The ice impinged on the side of the delicate shell, but was deflected by it and caused to scoop out a well defined frontal groove which was prolonged on each side of the shell in the usual manner, while in the lee of the obstruction a typical train about an inch in length was left in relief owing to the more intense abrasion of the adjacent surface. In this case, a thin, fragile silicified shell may be said to have turned a continental glacier from its course. As is evident the lateral pressure exerted against the shell was exceedingly small, probably not in excess of a few ounces to the square inch; the abrasive power of the moving ice was also exceedingly small as it failed to wear away a layer of quartz not over a tenth of an inch in thickness.

However powerful erosive engines glaciers may be when properly supplied with tools with which to abrade, the frontal grooves and tapering trains to be seen on many glaciated rocks and especially such instances of delicate work as just cited, furnish equally clear evidence that in the absence of tools they are nearly powerless to scour the surfaces over which they flow.

Chatter marks: Persons visiting localities where glaciated rock-surfaces occur in Northern Michigan, may also find still other examples of glacial inscriptions or markings the nature of which has been admirably described by Chamberlin, in the report referred to above. Among these records are "Chatter marks" in the bottom of strong grooves and assumed to have been produced by a vibration of the stone as it was forced along, which dug out the groove. These markings are curved cracks which cross the bottoms of glacial grooves from side to side, and as a rule present their convex sides to the direction from which the object came which led to their production. That is, if the ice moved from north to south, the chatter marks produced will present their convex sides to the north; but exceptions to this rule, or perhaps imitative markings have been noted, and chatter marks alone cannot be considered as decisive evidence of the direction a former glacier flowed.

Crescentic cracks: Crescent-shaped cracks of larger size than chatter marks, and usually occurring on flat rock-surfaces, seemingly independently of striæ and grooves, are also present at several localities in Northern Michigan. Examples of these crescentic "cross-fractures" as they have been termed by Chamberlin, occur on the south shore of Lake Duncan, and on a bare rock surface crossed by the road leading from Garden to Fayette near Garden Bluff (T. 39 N, R. 19 W.) where they are unusually abundant. The cracks are three to four or five inches long, and occur in series in the direction of ice movement, at intervals of two to perhaps four inches. Some of the series containing six to ten cracks, all curved in the same direction and presenting their convex sides to the northwest, the direction from which the ice came. Just how the cracks of this nature were produced is not known, but they are clearly glacial records, and seemingly furnish good evidence as to the direction of ice movement. The cracks penetrate the rock to the depth by estimate of two or three inches, and frequently endure when striæ and other of the more delicate records left by former glaciers have been obscured or removed by weathering. The presence of a series of parallel crescentic cracks separated by intervals of two to four or five inches, is sometimes all the evidence that remains of the former passage of a glacier over a rock outcrop.

GLACIAL DEPOSITS.

The vast continental glaciers which came from the north and advanced southward over Michigan, left records of their invasion not only in the form of inscriptions on the solid rocks over which they passed, as described in part in the last few pages, but deposited debris both directly and with the assistance of the streams formed by their melting. Two classes of superficial deposits thus originated; one glacial and the other fluvio-glacial.

Till: The material gathered by glaciers as they advance and deposited as they flow, or left when they melt, is known as till. In the region here considered the till consists very largely of a reddish, sandy clay, usually containing many angular or sub-angular stones and rounded rock masses. The larger stones whether angular or rounded, deposited by a glacier are termed boulders. The material which glaciers deposit directly without the assistance of streams, passes under the general name of moraines; but this term is applied more specifically to the irregular ridges and hills of sandy clay and boulders, accumulated about their margins, as lateral moraines, terminal moraines, etc., or concentrated on the surface of the ice as medial moraines. Such heaps and ridges are not present in the portion of Michigan described in this report, which means that the former glacier did not halt in that region and maintain a definite frontal alignment for a sufficient length of time to permit of the deposition of recognizable deposits of the nature just mentioned. If the ice lingered with a front extending cross the part of Northern Michigan referred to, it was so nearly clear of debris that no ridges or hills were formed. Glaciers under certain conditions of load, deposit material as they flow and on melting leave all of the debris previously contained in them, or present on their surfaces; in this manner a general sheet of rock-waste is deposited like a blanket over the country they occupied and mantles the hills and valleys. Such a sheet of glacially deposited debris is termed a till sheet; typical till being an unstratified sandy-clay well charged with sub-angular stones and boulders. It is material

of this nature which now constitutes the surface layer over large portions of Northern Michigan and adjacent regions.

Restricting attention to the land adjacent to lakes Huron and Michigan on the north, it may be said that a sheet of till was left over its entire surface when the former glaciers finally melted. Exceptions to this rule were probably furnished by precipitous slopes, such as the cliffs on the border of Mackinac Island, the face of Burnt Bluff, etc., but localities of this nature are rare, and most likely every ledge even on the faces of such precipices formerly had some glacially deposited material upon it. Since the ice melted which deposited the nearly universal till sheet referred to, many changes have occurred; the till has been washed from steep rock declivities by the rain, and rills and streams have cut channels through it, but the most conspicuous modifications are due to the wash of the waves and the action of currents in the waters occupying the basins of lakes Huron and Michigan, when they stood higher than at present. Below the old beaches, indicated on the map forming Plate XVI, the till has to a large extent been removed, assorted and redeposited through the action of lake water.

In physical composition the till in the region under consideration is nearly always reddish in color, conspicuously sandy, and contains numerous stones and boulders. The reddish color and sandy consistency is due, as seems evident, to the fact that much of it was derived from the red sandstone which is largely developed about Lake Superior, and probably now occupies much of the basin of that lake.

Two general classes of stones and boulders are present in the till; one class consists of limestone and dolomite fragments derived especially from the Trenton and Niagara formations which form the hard-rock surface of much of the region in question; and the other class embraces the stones and frequently rounded boulders of all sizes up to about three feet in diameter, composed of crystalline rock, such as is only found in place in the Lake Superior region, in Canada and in Northern Michigan to the west of the longitude of Marquette. As may be most reasonably inferred the boulders of crystalline rocks occurring in the drift to the north of Lake Huron, were derived principally from the portion of Canada lying to the north and east of Lake Superior; while the similar debris in the region north of Lake Michigan, was mainly derived from areas of crystalline rock to the south and southwest of Lake Superior. In reference to the relative proportions of locally derived, mostly calcareous material, and of the crystalline rocks brought from a greater distance, the former is nearly everywhere conspicuously in excess of the latter.

The nature of the stones contained in the till furnishes a means for determining from what direction the former glacier came, and the direction the ice moved, but as yet this criterion cannot be applied except in a few instances, as the rocks represented usually occur in place at more than one locality, or are not sufficiently characteristic to be readily identified.

There are two conspicuously characteristic rock outcrops, however, the debris from which can with certainty be referred to the parent ledges from which it was derived. These are: A red jasper conglomerate which outcrops in Ontario, to the north of North Channel, and about fifty miles north of Drummond Island; and the copper-bearing rocks of Keweenaw Peninsula.

The red jasper conglomerate is easily recognized by the angular fragment of bright red jasper it contains, embedded in a usually white, somewhat

vitreous quartzite base. Fragments of this rock frequently a foot or two in diameter, were observed on Drummond Island, about Hessel, on Bois Blanc, and other localities as far west as the St. Ignace Peninsula. Evidence is thus furnished that glaciers once covered the region to the north of Lake Huron, and moved southwest at least as far as the north end of Lake Michigan. This may not have been a single direct movement, but a general southwest flow of the glaciers at some time during the Glacial epoch in the region indicated is certainly shown by the distribution of jasper conglomerate just cited. Fragments of this same red jasper conglomerate are present in the glacial deposits of Southern Michigan, Northern Indiana and Ohio, and have been found in the vicinity of Cincinnati. A surprisingly wide distribution from a restricted area is thus shown to have occurred and taken in connection with other evidences indicates that the material laid down during one ice advance was removed and redeposited during one or more subsequent ice advances.

Native copper derived, as seems most probable at least, from the copper-bearing rocks of the Keweenaw Peninsula, has been found in the glacial deposits of Menominee county, on the Garden Peninsula, and as far eastward as the St. Ignace Peninsula, thus demonstrating that during some portion of the Glacial epoch there was an extensive ice movement over Northern Michigan from the northwest toward the east and southeast. Boulders of native copper have also been found in the glacial deposits of Southern Michigan and Ohio, thus showing as wide a dispersion by ice moving from the northwest, as do the boulders of red jasper conglomerate referred to above, in reference to the ice which came from the northeast. On the St. Ignace Peninsula, these two general movements overlapped as they did also over an extensive region to the south. Which was the earlier movement so far as is now known, is not definitely shown in Northern Michigan, although as will be stated later, in Menominee county the last ice invasion of that region came from the northeast and covered a till sheet containing native copper and fragments of iron ore, which had previously been deposited by a glacier moving from the northwest. In Southern Michigan, and the states adjacent on the south, much more definite information is recorded by terminal moraines, etc., than has yet been discovered in Northern Michigan, and a complex history has been deciphered by Frank Leverett and others.

The blanket of till covering the country under consideration is thin, not only in comparison with the glacial deposits of Southern Michigan, etc. but actually as measured in feet. From the east shore of Drummond Island westward to the north end of Lake Michigan, an estimate based on the records of a few wells and on the height of the present surface above observed rock outcrops, places the general depth of the superficial covering of rock-waste at from 20 to 30 feet. Practically all of this region, however, has been covered by lake waters, and the surface material has to a considerable extent been reassorted and concentrated especially just below the abandoned shore lines of the former lakes. Where the till has not been disturbed, as on the hills about six miles north of Hessel, on the summit of Mackinac Island, and about Allenville, etc., its thickness on an average is approximately from 15 to 20 feet. To the west of the St. Ignace Peninsula, numerous measures were obtained of the depth of the till sheet there generally present, and an estimate of from 10 to 20 feet may be taken as a general average of its thickness. To the south of the Minneapolis, St. Paul and Sault Ste. Marie railroad, on the triangular area terminating at the south in Point

Patterson, many surface exposures of the underlying limestone are present, and the greatest thickness of till obtained from the records of well, is 20 to 25 feet; the average for the area indicated is thought to be not over 10 to 15 feet. On Garden Peninsula to the south of the surface sand which occupies much of its northern portion, the covering of till is noticeably thin, many rock outcrops being present, and numerous well records available, and its average depth is certainly not over 10 feet. On the Bay de Noc Peninsula, a large amount of testimony gathered in part from farmers, shows that the thickness of the till which is spread quite uniformly over the level surface of the underlying limestones is on an average not over five feet. Throughout the greater portion of Menominee county, situated to the west of Green Bay, numerous hills composed of drift, termed drumlins, are present, and much more glacial debris was left on the underlying hard-rock surface than elsewhere in the region here considered. The hills referred to are in many instances about 40 feet high, and composed of till throughout, while in the intervening valleys the underlying rock although bare in places is usually from five to ten feet below the surface. The depressions or valleys occupy more space than the hills and for the entire country the average depth of till is probably not over 20 feet. Observation made on the hills about Metropolitan and Iron Mountain, show that in that region the true till sheet is from 10 to perhaps 15 feet in thickness, although in the low lands, considerably thicker deposits of the same material together with water laid sand and gravel are present.

The thinness of the sheet of morainal material left by glaciers over the portion of Northern Michigan described in this report, is in conspicuous contrast to the deep accumulations of similar material over all of the Southern Peninsula, and in fact of nearly the entire glaciated area of the United States from the Atlantic to the Dakotas. To the north of Lake Superior, however, as is known at least in a general way, glacial deposits are wanting over extensive areas, and bare and for the most part glacially abraded rocks are exposed. Northern Michigan thus appears to be situated between a region of glacial abrasion on the north and a region of glacial deposition on the south, but is more nearly related to the northern area. The facts presented above in reference to the small thickness of till in the part of the Northern Peninsula referred to, and the absence in that region of moraines, such as are formed about the margins of glaciers, together with the notable depth of glacial deposits, inclusive of surface-formed moraines, over the whole of the Southern Peninsula of Michigan, show that the change from abrasion to deposition in the case of the former glacier which covered Michigan, occurred in the region bordering Lake Superior on the south. It should be remembered, however, that glaciers may both erode and deposit at the same locality, at different times, and that deep glacial deposits may formerly have been present in North Michigan and later removed through the same agency which laid them down. In fact, as will be shown later, there is evidence of a conspicuous amount of ice erosion of previously deposited till in the region here considered.

DRUMLINS.

Among the characteristic changes in topography produced by the broad ice sheets of the Glacial epoch, both in Europe and North America, are smooth-surfaced, oval hills and ridges composed of till, the longer axes of which are parallel to the direction of flow of the ice which shaped them. These symmetric "lenticular hills," as they were at first termed in this country, are now designated as *drumlins*, a name first applied to them in Ireland and signifying a back or a ridge. Two types of drumlins have been recognized; one comprising short, broad forms, elliptical in ground plan, the longer axis only two or three times the length of the shorter axis, and measuring from a few hundred to perhaps two or three thousand feet in length; and the other consisting of long narrow ridges, in which the length is perhaps ten or twenty times the width, which attain lengths of from perhaps a mile to two or three or more miles. Between these two most common types, however, intermediate gradations may be found; and in many regions, more or less oval hills and ridges composed of till, approach in shape the true drumlin, but are less regular and less systematically arranged and may be termed *drumloids*. By this term is meant that the hills and ridges to which it is applied, approach or simulate typical drumlins in many ways, and are probably to be considered as incomplete or immature topographic forms of the same mode of origin.

In Northern Michigan two drumlin areas are known; one including Les Cheneaux Islands, and a portion of the adjacent mainland; and the other situated principally in Menominee county to the west of Green Bay. These two regions in each of which the dominant topographic forms are drumlins, are from 125 to 150 miles apart in essentially the same latitude, and are conspicuously different in the trend of the longer axes of the oval hills and smooth crested ridges which give them character. In Les Cheneaux area the direction of the last ice movement was from the northwest toward the southeast; and in the Menominee region from the northeast toward the southwest. The drumlins in each area were fashioned and given their characteristic shapes by the last ice sheet that moved over it, but the direction of ice movement in one of the areas, as just stated, was at right angles to the similar movement in the other area. This contrast in the direction of glacial flow is suggestive when taken in connection with the records of ice movement furnished by striæ, etc. on the solid rocks of the same general region and by the character of the boulders in the till, which can be traced to their parent ledges. That is, the details in the history of the Glacial epoch are far more varied and complex than is perhaps generally appreciated.

LES CHENEAUX DRUMLIN AREA.

An examination of the shore line about the Great Lakes as platted on the charts of the Northern and Northwestern lakes issued by the Corps of Engineers, U. S. army, shows that the outline of the land among Les Cheneaux islands and along the neighboring coast of the mainland, is conspicuously different from that of any other portion of the borders of the Great Lakes. The exceptional feature is the conspicuous parallelism in trend of the islands and of the capes on the adjacent mainland. Six measurements of the trend of the longer axes of the islands and capes made on the charts referred to

(reproduced in part on Plate V), give an average bearing of S. 52° 30′ E., with an extreme variation of less than one degree. Long narrow, stony ridges on the adjacent main land have the same trend as the similar ridges which form the islands and capes. In brief, the leading characteristic in the relief of the land and in the trend of the shore line, is furnished by a series of long, narrow parallel hills, part of which stand on the land and a part in the water. These hills are composed of till and have other characteristics of drumlins. As the reader will infer from these statements, Les Cheneaux Islands, owe their peculiar and conspicuous alignment to the fact that a group of drumlins is there partially submerged by the water of Lake Huron. This conclusion is rendered still more evident when the relief of the islands is also considered, as their surfaces present ridges and troughs, similar to the corresponding features about the neighboring villages of Hessel and Cedarville. The larger islands bear on their surfaces groups of parallel ridges trending northwest and southeast, the troughs between the ridges being above water except at their ends where narrow bays extend into the land. A number of the smaller islands as Richard, Isadore, etc., which consist of a single straight ridge with rounded cross-profile are individual drumlins. In a few instances as shown on the Lake Survey charts, the ends of islands and of capes are hooked or barbed, as for example the northwest end of Boot Island, and the extremity of the cape where Hammel's fishery is located. A visit to these localities showed that the exceptional outlines they present are due to wave action along the shore, such as the building of spits, or connecting bars between islands, etc.

The trend of the longer axes of a group of drumlins as already stated, is as a rule parallel to the direction of flow of the glacier which shaped them. This test can be applied to the long narrow hills in the Les Cheneaux region. On a flat limestone surface about one mile north of Hessel and crossed by the road leading north from that village, glacial striæ and associated markings are well exposed. The general direction of ice movement thus recorded, is from northwest to southeast, and indicated on the map forming Plate XVI. Two series of striæ, etc. are present; the stronger, and as the evidence seems to show, the earlier series, trends N. 70° W. (an average of six measurements with a range of 10 degrees); crossing this series is a series of more delicate striæ, bearing N. 57° W. (three readings being the same). The trend of Les Cheneaux Island as stated above is S. 52° 30′ E. This as nearly as can be determined is also the trend of the longer axes of the ridges, as measured along their summits; the trend of the hills thus corresponds approximately with the direction of the lighter series of striæ on the adjacent rock surface; the difference being four and one-half degrees. In this instance the ice at the time the hills were given their present symmetrical shapes, crossed a previously scored rock surface but left only a delicate inscription upon it.

The drumlins at Les Cheneaux, are of the elongate type, being in several instances from one to two miles in length, with a maximum width of from about five hundred to eight hundred feet in the largest examples and with a height above the intervening troughs of forty to about fifty feet. How many drumlins there are in the group is not definitely known, but there are certainly fifty and perhaps twice that number may be present. They are composed of compact clayey till of a reddish color and contain many large boulders. The boulders are in part composed of limestone and are of local origin, and in part of crystalline rocks such as occur in places in the neighboring portion of Canada. At one excellent section across a drumlin

at Cedarville, where a cut for a road has recently been made, the stiff clay is laminated, the laminæ being distinct in the upper five or six feet of the exposure, but less evident and seemingly wanting at a greater depth. The laminæ are curved and parallel with the convex surface of the ridge as exposed in cross sections.

One of the most conspicuous features of the drumlins forming Les Cheneaux Islands, etc., is that their surfaces are strewn with a multitude of boulders. This feature is well shown by the photograph forming Plate VI, A, taken at Hessel. This roughness of surface and abundance of loose boulders is exceptional to the normal condition of the surfaces of drumlins, which as a rule are conspicuously smooth and even. Its explanation lies in the fact that the waters occupying the Lake Huron basin were formerly higher than at present, and the waves and currents working on the drumlins removed much of the fine material from their surfaces and thus concentrated the stones and boulders. In their present condition they may be termed washed drumlins. At one stage in the history of the basins of the Great Lakes the water was about 200 feet deep at Les Cheneaux Islands the shore line being then about six miles to the north, where islands were present in Lake Algonquin as the former water body has been named. The washing, however, which removed the finer material from the surface of the drumlin, as just mentioned, occurred when the lake waters were at a lower level and principally when they stood about forty feet above their present horizon and what is known as the Nipissing beach was produced. The position of this old lake margin is shown by gravel terraces on the sides of some of the drumlins about Hessel and is particularly well marked at Cedarville.

MENOMINEE DRUMLIN AREA.

Distribution: Well defined and characteristic drumlins occur over the greater portion of Menominee county, with the exception of the sandy region five to six miles wide adjacent to Green Bay, and perhaps extend northward into Marquette county and westward into Dickinson county. The drumlin area is more extensive than the one at Les Cheneaux Islands, and is thought to embrace about 750 square miles. The number of drumlins is certainly many hundred, and possibly several thousand, but no reliable estimate in this connection can as yet be made. The most characteristic portion of the area so far as now known, lies between Wallace on the south, and Northland on the north, and in an east and west direction, between Ford River station and Hermansville. The drumlins are numerous along each of the railroads radiating westward from Escanaba within the region just indicated, and are especially abundant along the line of the Chicago and Northwestern railroad between Bark River and Powers. Perhaps the best localities for observing them is in the vicinity of Wilson, Spalding, Powers, Hermansville and thence southward to Stephenson.

Absence of solid-rock cores: The region just designated is underlain by Trenton limestone which is approximately horizontal, and has a nearly even surface. No suggestion of rocky knobs or other elevations that might have served as nuclei for the accumulation of glacial debris are present.

Shape: The drumlins are largely of the elongate or ridge like type, many of them being from half a mile to two miles long, while some are yet more extended. Their widths are in numerous instances, from 300 to 800 feet in the widest part. A typical example, the first one cut by the Chicago and Northwestern railroad to the west of Indian Town, measured by pacing,

is 9,000 feet in length, and 750 feet wide in the central part; and has a maximum height of 30 to 35 feet above the adjacent marshy troughs. It tapers gradually in both width and height from the center toward each end and terminates in each direction in a well defined obtuse point. Several neighboring examples have similar dimensions. The ratio of width to length in these instances is in general about as one to twelve or fourteen. In some of the smaller examples near Spalding, this ratio is approximately one to two or three.

Trend: The general trend of the longer axes of the drumlins is northeast and southwest, but considering the entire area there are conspicuous variations in this particular. While neighboring drumlins as for example throughout a distance of a mile measured at right angles to their general trend, are in some instances strictly parallel, in other instances a divergence of trend of their larger axes amounting to fully fifteen degrees as observed. Throughout the portion of the area which was traversed the extreme variation in trend is between N. 12° E. and N. 55° E. These variations seem to have an orderly sequence and the drumlins over a large area to swing symmetrically, but not enough observations are in hand to make this conclusion definite.

Uniformity in elevation: A more conspicuous feature than the general parallelism of the drumlins is their nearly uniform height. An observer standing on the highest portion of the crest of any one of the larger examples and examining the neighboring drumlins with the aid of a hand level will find that all of the larger ones in view rise to the same level with a variation of less than five feet. Some of the smaller examples fail to reach the summit level of their larger companions, but no drumlins rise above that level. In other words, if the depressions and valleys between the drumlins were filled to the level of the summit of the majority of them, a horizontal or essentially horizontal plain would be produced.

Height: The height of the drumlins above the bottoms of the intervening valleys is in general from thirty-five to forty feet; the variation being due to the depth to which the valley has been excavated, and the amount of stream deposited sand and gravel or peaty material present in them.

Rock striæ: Exposures of rock surfaces between the drumlins are somewhat common, and at one locality about one mile east of Spalding, on the line of the Chicago and Northwestern railroad, a glaciated limestone surface bears glacial striæ and related markings, which record an ice movement from the northeast toward the southwest. The striæ bear N. 38° E. That is the direction of glacial flow as recorded by striæ, etc., is substantially the same as the trend of the longer axes of the drumlins; it is worthy of note, however, that the drumlins nearest to the locality where the striæ were observed, trend N. 55° E.

Composition: The drumlins with the exception of a thin surface layer, are composed of reddish, sandy till charged quite uniformly with stones and boulders. Their appearance in section is well shown on Plate VI B. Many of the stones are angular fragments of Trenton limestone, derived from near at hand, but the larger and more conspicuous boulders are of hard crystalline rock and usually well rounded. In certain of the drumlins near Powers, the limestone fragments amount to fully eighty-five or ninety per cent of the rock-masses present which are a foot or more in diameter. Of the finer material between the stones and boulders quartz sand constitutes a conspicuously large proportion. The limestone fragments are mostly flat masses broken from strata from two to six inches thick and are without orderly

[illegible] having 50 meshes to linear inch	6.73 per cent.
[illegible] on a sieve having 100 meshes to linear inch	11.21
Passed through sieve having 100 meshes to linear inch	15.71
	66.35
Total	100.00

Of the portion of the sample which passed through a 10 mesh sieve, 20.05 per cent was soluble in hydrachloric acid, and may be termed a dolomite rock-flour.

Powers, the limestone fragments amount to fully eighty-five per cent of the rock-masses present which are a foot or more in diameter. Of the finer material between the stones and boulders quartz sand constitutes a conspicuously large proportion. The limestone fragments are mostly flat masses broken from strata from two to six inches thick and are without orderly

arrangement; that is, the flat blocks are packed in the enclosing sandy-till with their longer axes pointing in all directions.

Absence of lamination: In no instance was the lamination observed, which is sometimes stated to be peculiar to drumlins. This feature as cited on a previous page, is present in the clayey till of the drumlins at Cedarville, and its absence in the drumlins under consideration, suggests that it is dependent on the physical condition of the till of which drumlins are composed, and is to be expected in those consisting largely of clay but not in those composed of decidedly sandy till.

Copper and Iron boulders: In certain of the drumlins near Powers, Nadeau and Daggett, several battered and scratched masses of copper have been found, and also large fragments of specular iron ore. These boulders as already stated, were no doubt derived from the copper and iron-bearing formations which come to the surface in Northwestern Michigan and show that the glacier which transported and deposited them moved from the northwest toward the southeast. The trend of the striæ on a rock surface near Spalding, and the general alignment of the drumlins as already stated, point conclusively to an ice movement from the northeast toward the southwest. The bearing of the evidence thus furnished, of two ice movements, —the later being at right angles to the earlier—on the theory of the origin of drumlins will be considered later.

Surface material: The surface portions of the drumlins as stated above, differ from the material beneath. As observed in a large number of instances their surfaces to a depth of about a foot or eighteen inches, are uniformly covered with a layer of fine dustlike loamy sand. This material when examined under a microscope is seen to consist principally of angular grains of quartz, but mingled with the determinable grains are fine, brownish, amorphous particles. It is so fine that 66.35 per cent of it will pass through a sieve having one hundred meshes to the linear inch.[1] This fine surface soil is exceedingly favorable to agriculture and for this reason the drumlins throughout the Menominee area, have to a great extent, been cleared of forests, and are now under cultivation. Mingled with the fine dust-like material of the surface layer are numerous stones of all sizes up to boulders fully three feet in diameter. These surface stones are to a great extent limestone fragments, but a few and including the larger ones, are of crystalline rock. In many of the fields on the drumlins, the surface stones have been removed and piled in large heaps, leaving a surface of conspicuous evenness composed of fine rich loam. Where the stones have not been removed they form a pronounced feature of the surface.

Irregularities: Normal drumlins, as is well known, are smooth oval hills without irregularities; while the majority of the drumlins in the Menominee region fulfill these conditions, there are certain notable and suggestive exceptions. It is difficult to classify the irregularities referred to, but they may at least provisionally be termed transverse trenches, side trenches, surface pits, and asymmetry in ground plan and marginal slopes.

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1 An average sample of the soil freed from pebbles, and subjected to mechanical analysis in the presence of water, gave the following results:

Retained on a sieve having 10 meshes to linear inch	6.73 per cent.
Retained on a sieve having 50 meshes to linear inch	11.21
Retained on a sieve having 100 meshes to linear inch	15.71
Passed through sieve having 100 meshes to linear inch	66.35
Total	100.00

Of the portion of the sample which passed through a 10 mesh sieve, 20.05 per cent was soluble in hydrochloric acid, and may be termed a dolomite rock-flour.

Transverse trenches are trench-like depressions through a drumlin at right angles or nearly so, to its longer axis and in the case of the deeper examples resembling railroad cuts. Their bottoms are frequently on about the same level as the adjacent troughs or valleys but in some cases are less deep. In no instance were deposits observed in the marginal troughs at the ends of the trenches, of the nature of alluvial cones, such as would suggest that the trenches are due to the action of streams since present conditions obtained; although in certain cases a small amount of gravel has thus been washed out of them and deposited at their ends. Good examples of the kind of irregularity here considered and in fact of several of the irregularities mentioned above, may be seen in the first drumlin cut by the Chicago and Northwestern railroad to the west of Indian Town. Another typical instance is present about one mile southwest of Wilson and to the south of Cedar River. The most instructive example thus far seen, however, occurs near the southwest end of a drumlin about half a mile northwest of Spalding (in the N. E. quarter of section 9, T. 38 N. R. 26 W.) In this instance an esker, as will be described more fully later, which follows an irregular east and west course, approaches the transverse cut in the drumlin from the east, and at the west end of the cut continues its course westward. The conditions are such as to show that the esker was deposited by a sub-glacial stream which excavated the trench across the drumlin.

Side trenches are cuts in drumlins which begin near their crests and extend down one side, becoming deeper and broader as the adjacent valley is approached. In a number of instances the depressions referred to head well to one side of the crest of a drumlin, cut through its axis and open out into the trough on the opposite side, thus showing most of the features of the transverse trenches, but having a distinct proximal end. For example, in the first drumlin west of Indian Town and near its northeast end, an excavation begins on the southeast side of the drumlin and only a few feet above the level of the marginal trough on that side, and extends toward the northwest through the drumlin and opens out on a level with the interdrumlin trough on that side. These trenches are usually nearly straight, but in some instances their courses are conspicuously curved.

Each of the types of trenches just noticed, is favorable for the passage of roadways and in several instances they have been utilized for this purpose.

Surface pits are irregular depressions in the surfaces of drumlins, which have no draining channel and in at least one instance, at the south end of the Indian Town drumlin, retain sufficient rain water to form a small swampy pool. The pits are from perhaps ten to thirty or fifty feet across, and in many instances five to seven feet deep. These occur principally on the summits of the drumlins both in their central and terminal portion. Numerous examples of these irregular pits were observed but many drumlins are free from them.

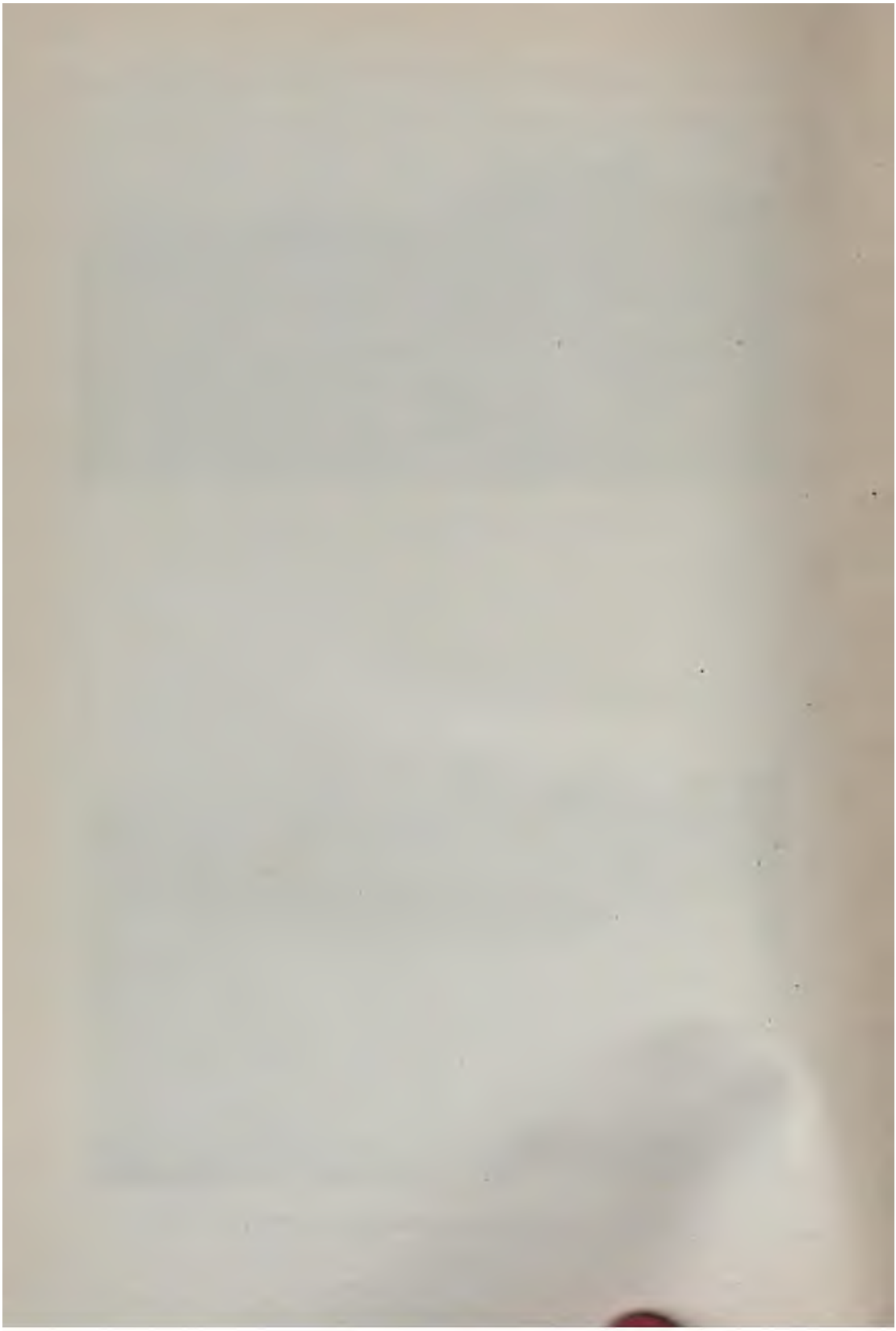
By asymmetry in ground plan, is meant an irregularity such as would be produced if a portion of the side of drumlin should be eroded away, as by a stream for example, leaving a steep bluff. Irregularities of this nature are rendered conspicuous by reason of the exceptional steepness and boldness of the slopes they present, which are in striking contrast to the smooth undulations of the lines characteristic of a drumlin landscape. Two examples of the asymmetry referred to, were observed; one on the northwest side of a large drumlin situated partially in section 3 and partially in section

A.—SURFACE OF WASHED DRUMLIN NEAR HESSEL.

July 10,1904.

B.—SECTION OF A DRUMLIN NEAR POWERS.

September 1, 1904.



10, about one mile northward of Spalding; and the other on the southeast side of a large and otherwise characteristic drumlin, crossed by the road leading south from the same village and three miles distant. The former has a steep bluff on its northwest margin, and the latter a similar bluff on its southeast margin. In each case the regularity of the elliptical ground plan of the drumlin is rendered irregular by a flattening or straightening of its curvature where a steep bluff occurs.

The grooves and valleys between drumlins: The drumlins in certain instances as about Spalding, and Powers, and thence southward to the vicinity of Daggett, may be said to occupy as much ground space as do the intervening depressions. In many portions of the region referred to, the depressions between the drumlins form the exceptional feature in the landscape, and call for an explanation rather than the smooth oval hills they surround and separate one from another. The depressions are normally broad, shallow concave troughs (Plate VIII, B) which widen adjacent to the ends of the drumlins and become narrow where the drumlins broaden in their central portion. The troughs like the hills they separate, have smooth, flowing outlines, and even surfaces, except where gravel and sand in the form of eskers and kames have been heaped up within them. If accurately mapped they would be found to have a current-like arrangement, analogous to the shallow channels between the numerous sand bars and islands of an overloaded or "braided stream," such for example as the Platte River at low water.

A characteristic example of the grooves to which attention is here directed, is associated with a small drumlin, about one mile northwest of Spalding, (it is crossed by the road between sections 4 and 9, T. 38 N. R. 26 W. and lies principally in the N. E. ¼ of the N. W. ¼ of section 9.) It is one of a cluster of four or five closely united drumlins and is situated on the southern side of the general mass and on a southward descending slope. Its length is about one thousand feet, width in central part approximately two hundred feet, height about twenty-five feet, and trend N. 48–49° E. About the northeast end of the drumlin and extending all the way along its eastern side, and for about half the length of its western side, there is a distinct, round-bottomed groove about twenty-five or thirty feet wide and ten to twelve feet deep. This groove is evidently a result of erosion by flowing ice and has been excavated in till. The absence of the groove as a distinct feature on the southwest side of the drumlin, is owing to the fact that the slope there descends into the valley of Cedar River and other topographic conditions prevail. Some of the features just described are shown on Plate VIII.

The groove just described, recalls to mind the frontal grooves with side extensions, to be observed on many glaciated rock-surfaces where hard bodies are embedded in softer material, but while such grooves are usually less than an inch across and a fraction of an inch deep, the one in question is measurable in feet as just stated. The similarity in form in these two instances is conspicuous, however, and tends to strengthen the conclusion that the groove about the drumlin is due to ice erosion.

The groove about the proximal end and along the sides of the drumlin near Spalding is similar to many other grooves and shallow depressions between neighboring drumlins in the Menominee region and leads to the suggestion that the drumlins throughout that region have been given their prominence principally by the erosion of the grooves and valleys separating them.

Terrace on the side of a drumlin: The drumlin here considered is situated about one and one-quarter miles northwest of Powers, on the branch of

the Chicago and Northwestern railroad which connects Powers with Iron Mountain. The railroad crosses the drumlin by means of a cut about eight hundred feet long and thirty to forty feet deep in the central part; in the sides of the cut, good exposures of the normal reddish, sandy and bouldery till of the region may be seen. The trend of the drumlin is N. 53° E. or about at right angles to the railroad track, and its length by estimate in the neighborhood of one mile.

The drumlin is normal in every way so far as seen, except that on its southeast side there is a terrace-like flattening of the slope about midway between its base and summit. In cross profile the surface of the terrace is about thirty feet wide and slightly concave. It can be traced nearly the entire length of the drumlin and in longitudinal profile is convex upward, being parallel with the crest line of the drumlin on the side of which it occurs.

Hypotheses as to the origin of the drumlins of the Menominee region and explanations of the irregularities they present will be considered later. As the drumlins are intimately associated with another class of topographical forms, namely eskers, it is convenient to insert here a brief record of such observations as were made concerning them.

ESKERS.

Under this name have been grouped certain irregular, winding ridges composed of crossbedded or current-bedded gravel and sand, which occur in regions formerly occupied by ice sheets. Their lengths are from a few hundred yards to many miles, the shorter ones in numerous instances being clearly disconnected portions of what would otherwise be conspicuously elongated examples. In width they measure from a few score feet to several rods, and their heights are equally variable, being at times only a few feet and in other instances one or two hundred feet. One of the chief peculiarities of these irregular ridges, is that they cross the regions where they occur with but slight if any reference to other features of the relief. The name *esker* has been applied by Irish geologists to the class of ridges here considered; in Scandinavia they are known as *osar*, but the former term seems preferable.

As to mode of origin, the eskers are considered perhaps by most students of glacial phenomena, to have been formed by streams flowing in tunnels at or near the bottoms of glaciers, but hypotheses assigning them to the work of streams flowing in open cuts in ice sheets have been advanced, as well as other explanations.

In the Menominee region eskers are numerous and have a significant distribution in reference to the drumlins with which they are intimately associated. Most commonly they occur in the troughs or valleys between drumlins, and in a general way trend with the longer axes of the drumlins with which they are most nearly associated. In certain instances, however, they cross the trend of the drumlins approximately at right angles and in a few cases are superimposed upon them.

Eskers in the valleys, which follow the general trend of the associated drumlins, occur in the immediate vicinity of the several branches of Cedar River, particularly to the northward of Spalding, but are also frequently present in valleys that have only insignificant draining streams, or none at all. In this connection it is suggestive to note in reference to the mode of origin of eskers, that the streams of the region under consideration, flow between or about the numerous drumlins, and, do not cut through them.

A.—DRUMLIN HALF A MILE NORTHEAST OF SPALDING; LOOKING EAST.
September 5, 1904.

B.—DRUMLIN TOPOGRAPHY NEAR NADEAU, LOOKING SOUTH, SHOWING GROOVE BETWEEN DRUMLINS.
September 7, 1904.

That is, the streams are consequent to the relief of the surface as produced by glacial agencies, and have modified that surface to only a slight degree. The streams wind about the bases of the drumlins, but so far as observed have not cut into them so as to break their normally even and flowing outlines. The greater number of the eskers follow similar courses and occur in the immediate vicinity of streams which they parallel in a general way. In many instances the streams have cut trenches through the eskers.

But one conspicuous example of an esker extending in a direction approximately at right angles to the longer axes of the associated drumlins has been observed. The one referred to, was mentioned on page 74 in connection with a description of a transverse cut in a drumlin about half a mile northwest of Spalding, and is crossed by the road leading north from that village. It has an irregular east and west course across open fields and from the road is in sight for a distance of about half a mile. At the west it approaches the east end of a trench in a conspicuous drumlin situated in the N. E. ¼ of Sec. 9, T. 38, R. 26. The same esker is again crossed by a road leading northwest from Spalding near the center of section 9, and to the south of a cemetery. To the east of the cemetery the esker follows an irregular course across a field to the west end of the trench which cuts the drumlin. This association of the eskers with a trench across a drumlin is good evidence that both the esker and the trench owe their origin to the same cause; namely a subglacial stream which deposited the gravel and sand of the esker and excavated the trench across the drumlin with which it is intimately associated.

An example of an esker perched upon the summit of a drumlin, is furnished by a prominent ridge immediately south of Wilson, which is about a mile long, seventy to eighty feet high in the central portion, and trends N. 32° E. The extreme northeast end of the ridge is crossed by the Chicago and Northwestern railroad by means of a shallow cut in the sides of which coarse gravel is exposed. The main portion of the surface of the ridge is also composed of gravel and sand but its southwest end consists of till and has the smooth flowing contours characteristic of drumlins. The compound ridge in its summit portion is conspicuously higher than any of the numerous drumlins in sight from its summit. This exceptional height, together with the facts just noted, indicates that an unusually large esker for the region where it occurs, was deposited on the summit of a drumlin, the longer axes of the two coinciding, but at the southwest the till of the drumlin extends farther than its covering of water-laid material.

The conditions pertaining to the prominent ridge near Wilson are repeated on a smaller scale at a locality about one mile east of Nadeau, or more precisely at the corner common to sections 8, 9, 16 and 17, T. 37 N. R. 26 W. At this locality there is an irregular hill trending about N. 43° E. which by estimate is fifty to sixty feet above the adjacent swampy valleys, and as is evident to a person standing on its summit, is higher than any other of the numerous hills in sight. The summit portion of the hill is composed of sand and well rounded gravel but to the southeast this material terminates in a steep slope about fifteen feet high and the continuation of the ridge is composed of till and has the contours and other features normal to drumlin. In this instance, however, the deposit of gravel and sand on the summit of the drumlin, lacks the characteristic ridge form, conspicuous at the esker near Wilson, and the deposit may perhaps be of the nature of the gravel and sand hills described below.

KAMES.

This name has been given to irregular heaps of gravel and sand, made by streams in association with glaciers, but without the extended ridge-like form peculiar to eskers. Kames as a rule, occur as more or less isolated groups of irregular knolls and hills, with underdrained depressions among them; their general arrangement being parallel with the margin of the ice sheets about, or perhaps in part beneath, which the material composing them was deposited.

Kames are present in the Menominee region but they are less common and less conspicuous features of the relief than are the eskers, and as it seems, one form grades into the other. A characteristic group of kames occurs about a mile and a half south of Wilson, south of Cedar River, in section 18, T. 38 N. R. 26 W.

Comparisons: The drumlins, eskers and kames, of the Menominee region, present certain characteristic differences, which make them easy to distinguish one from another and are also of economic significance.

The drumlins are conspicuously smooth, and at the surface are composed of exceedingly fine sandy loam which makes them highly valuable for agricultural purposes. The soil is porous and absorbs all the water that comes to it as rain, or from melting snow, and even on steep slopes in plowed fields, is not scored by rill channels. Owing to the excellence of the soil on the drumlins they are to a great extent, cleared of native vegetation and under cultivation. For farming purposes they furnish the best conditions found in any considerable portion of northern Michigan.

The eskers are composed of coarse material, are unfavorable in most instances for agriculture, have conspicuously uneven surfaces and although partially cleared in many instances, are usually left bristling with stumps and the dead trunks of trees and serve best for pasture lands. The absence of fine soil over the eskers is apparently due to its having been washed down into the open spaces in the coarse, loose material beneath, for as will be stated later, it seems that the eskers like the drumlins must at one time have had a thin surface sheet of fine silt-like material on their surfaces.

The kames, judging principally from the nature of the group of hills a mile and a half south of Wilson, are composed of finer material than the eskers, and in reference to agriculture are nearly as favorable as are the drumlins. Both eskers and kames, like the drumlins are unscored by rill channels. Throughout the entire Menominee region, in fact, with the exception of the bottom of certain of the larger valleys, the topography is still in almost precisely the same condition that it was when the region was abandoned by the ice sheet and associated streams, which gave it shape and character. That is, post-glacial changes are trifling and over large areas are practically absent.

The entire Menominee region was until recently entirely forest covered, and probably more than half its area is still occupied by trees and shrubs. A conspicuous difference between the drumlins and eskers, in reference to their relation to the trees which once grew upon them, is that the fine soil and till sub-soil of the drumlins, gave a good anchorage for large trees, while the trees growing on the loose-textured gravel-ridges were less securely rooted. On the drumlins there is but little evidence that trees have been uprooted by storms, but on the eskers the characteristic mounds with accompanying depressions which overturned trees produce, are a common and characteristic feature.

A.—DRUMLIN WITH FRONTAL AND SIDE GROOVE, ONE MILE NORTHWEST OF SPALDING; LOOKING SOUTHWEST.

September 5, 1904.

B.—DRUMLIN WITH FRONTAL AND SIDE GROOVE, ONE MILE NORTHWEST OF SPALDING; LOOKING NORTHEAST FROM TOP OF THE DRUMLIN.

September 5, 1904.

ORIGIN OF DRUMLINS AND ESKERS.

On the preceding pages considerable evidence has been presented concerning the nature of drumlins, eskers and kames. It now remains to sum up this evidence and learn to what conclusion in reference to the mode of origin of the topographic forms referred to, it lends support.

The drumlins of the Menominee region share certain characteristics in common, while a few of them present individual peculiarities. Any hypothesis to account for their origin should, therefore, explain each of these two classes of conditions in order to be worthy of acceptance:—

Their like features are: the till of which they are composed is of the same general nature in all instances, there is an absence of lamination, the flat stones present have no orderly arrangement or orientation, a thin surface layer of fine silt-like material associated with many stones and boulders is seemingly always present, they have the same general shape and the same general alignment.

Their unlike features are: transverse trenches, lateral trenches, surface pits, frontal and side grooves, asymmetric ground plan, et cetera, as described above, which are present in certain and relatively few examples but usually wanting.

The till of the drumlins, as has already been stated, contains boulders of native copper and of iron ore, showing that it was deposited by an ice sheet which flowed from the northwest toward the southeast: while the trend of the longer axes of the drumlins and the striæ observed in one instance on a rock surface exposed in their midst, record an ice movement from the northeast toward the southwest.

The best translation of the records just summarized with the aid of current knowledge in reference to the nature of glaciers and the various discussions as to the origin of drumlins that have been publishd, is as it appears, the following:

A till sheet about fifty feet thick was spread with a conspicuous degree of uniformity over the Menominee region by an ice sheet which came from the northwest; afterward, this ice sheet melted, or a change occurred in the direction of its flow and a movement from the northeast became general. During the later stage of glaciation the ice eroded the till over which it flowed, and excavated grooves and valleys and pressed and moulded the intervening ridges into the smooth oval hills and ridges which are now present. As the nearly clear ice melted, which eroded the previously deposited till, it left a thin sheet of fine material (as is presumed composed largely of dust which accumulated on the ice) together with loose stones and boulders, over the surface of the land it vacated. On the drumlins this surface sheet or dustlike material still remains, but on the coarser textured eskers it has been carried down into the interstices in the gravel beneath by percolating rain water. In the shallower grooves between the drumlins the fine material is also still present but in the broader and deeper valleys it has not been observed and presumably is concealed beneath subsequently formed peaty soils.[1]

The last glacier which covered the region, as has been stated, excavated the till over which it passed, but did not remove it uniformly in all places. The ice, as seems to be well shown by the grooves and channels it left, flowed in currents which were somewhat flexible and curved about and among

1 The surface covering of fine silt-like material, may in part have been deposited as dust during the post-Glacial time, but as the region was formerly forested, the contributions from this source were probably not great.

the masses of till which remained. Over certain areas ice erosion was more intense than at other localities, and all the till was removed and the hard rocks beneath striated. The hypothesis of ice erosion thus seems to account for all the normal characteristics the drumlins present.

As shown especially by the frontal groove in connection with a drumlin near Spalding, the current in the basal portion of the eroding ice-sheet was deflected, as it seems by some apparently moderate irregularity in the resistance of the till it rested upon. Similar deflections when they caused an ice current to impinge on the side of a previously well shaped drumlin, eroded it and if the process was checked by the melting of the ice, before the drumlin was completely removed, an unsymmetrical drumlin with a portion of one side removed and a steep bluff produced, would result. Examples of such irregularities as already described, are furnished by a drumlin one mile northeast of Spalding which has been eroded on its northwest border, and by a drumlin three miles south of Spalding, which has been eroded on its southeast border.

The pits in the surfaces of the drumlins can be accounted for on the assumption that depressions were present in the surface of the till sheet before it became eroded, the depressions being occupied by stagnant ice over which the moving ice passed by shearing; or else the material of the drumlin has settled unequally since it was formed. I am strongly inclined to accept the first of these two alternatives, but other explanations may be forthcoming.

The transverse and side trenches present in certain of the drumlins, all though in part perhaps, like the surface pits, to be ascribed to depressions in the till before ice erosion began, are evidently in most instances due to corrasion by running water. The material removed however, is not present in the condition of alluvial fans etc. in the adjacent, and in certain instances streamless valleys,—the exceptional case when an esker is in line with a transverse trench will be referred to below—and from this it is safe to conclude that the water corrasion did not occur since the melting of the last ice sheet which occupied the region. The uniformly smooth surfaces of the drumlins and the entire absence of rill channels upon them, is strong collateral evidence in favor of this same conclusion. If the transverse and lateral trenches were not excavated since the melting of the ice sheet which gave shape to the drumlins, they must have been formed while the ice was still present. This conclusion is in harmony with the accepted explanation of the origin of eskers, and is a warrant for the farther conclusion that streams of water flowing in ice tunnels or in ice channels were present.

The intimate association of an esker with a transverse trench in a drumlin, referred to between dashes above, is highly instructive, as it shows in what portion of the glacier the streams were situated which cut the trench and deposited the associated esker. That is, the stream was sub-glacial, or nearly so, since the crest of the drumlin across which it excavated a channel is only about twenty feet above the bottoms of the adjacent troughs.

The only remaining irregularity of the drumlins under consideration to be re-considered at this time, is the terrace-like shelf on the side of a drumlin, one and a quarter mile northwest of Powers, described on pages 75–76 This terrace it will be remembered, is on the side of the drumlin, has a convex curvature in the direction of its length, and is parallel or nearly so with the curvature of the longitudinal crest-line of the drumlin with which it is associated. Now, at several localities in the same general region, drum-

A.—ESKER NEAR CEMETERY, HALF MILE WEST OF SPALDING, LOOKING NORTHEAST. September 5, 1904.

B.—ESKER HALF A MILE NORTH OF SPALDING, LOOKING NORTHEAST. September 5, 1904.

lins are present in close juxtaposition, but separated by a round bottomed groove. They have a relation one to another, to use a familiar comparison, similar to that of loaves of bread baked in the same pan; that is, the groove between two adjacent drumlins is all that serves to differentiate them. If two loaves of bread which have become united along their sides while in the oven are broken apart, a scar remains on each one; so in the case of two drumlins which are united along their sides, if one is eroded away an irregularity or scar showing where it was formerly united with its neighbor may remain. The terrace on the side of the drumlin referred to above, is of the nature of such a scar; the companion drumlin having been removed by ice erosion, but leaving a portion of the bottom of the groove which formerly separated the two. It thus appears that both the normal and the abnormal features of the drumlins of the Menominee region can be consistently accounted for on the hypothesis of ice erosion of a previously formed till sheet, and that this as it seems must be the true explanation of the origin of the drumlin of that region. This explanation is not new, but is essentially in harmony with an hypothesis of the origin of drumlins proposed by N. S. Shaler[1] several years since, but as it seems, not generally accepted by geologists.

Other explanations of the origin of drumlins as is well known, have been advanced[2] but a general discussion of them cannot be undertaken in this report. I need scarcely warn the reader that the conclusion reached above, in reference to drumlins having resulted from the ice erosion of a previously deposited till sheet, relates to the Menominee region simply, and is not at present advanced as a general explanation applicable to all drumlins.

FLUVIO-GLACIAL DEPOSITS.

Under this title students of glacial phenomena group a considerable number of deposits with various topographic forms, which are due to the work of streams in intimate association with ice sheets. Examples of two classes of such deposits in the Menominee region, namely eskers and kames, are described above. A third class, termed valley trains and outwash plains, have a wide development in Northern Michigan and the adjacent portion of Wisconsin, but to only a minor extent enter the strip of country adjacent to lakes Huron and Michigan which is especially considered in this report.

Valley trains and outwash plains consist of cross-bedded sand and gravel, which has been washed out of a glacier and deposited about its margin and in depressions in the land leading away from it. Such deposits as a rule have even, gently sloping surfaces, but are sometimes conspicuously pitted or contain large irregular depressions, owing to the melting of ice which was contained in or surrounded by the sand and gravel at the time of its deposition. When these features are prominent in an outwash plain it becomes a "pitted plain," and the depressions frequently contain lakes.

Sand and gravel plains of the nature just noted, are a common feature in North Michigan, particularly to the north of Little Bay de Noc, and as is judged from the reports of persons familiar with the region mid-way be-

[1]Boston Society of Natural History Proceedings, vol. 13, 1870, pp. 196–204; see also, U. S. Geological Survey, 7th Annual Report, p. 321.

[2]The nature and origin of drumlins has been well discussed by Warren Upham, and many references to the literature of the subject given, in Boston Society of Natural History Proceedings, Vol. XXIV, 1889, pp. 228–242, and Vol. XXVI, 1892, pp. 2–25.

tween Lake Michigan and Lake Superior are there extensively developed. The plains referred to are commonly designated as "jack-pine plains" but other sandy areas have similar characteristics of forest growth. Pitted plains occupy an extensive area to the west of Iron Mountain, and extend into Wisconsin, but this area, like the greater part of the jack-pine plains referred to lies outside the region here especially considered.

The only localities where sand plains of fluvio-glacial origin form a conspicuous feature of the region described in this report, are on the west border of Little Bay de Noc, as at Gladstone, and thence northward along the west side of the valley occupied by Rapid and White Fish rivers, and on the east border of the same valley from near Ensign northward. This valley now in part submerged, is a little over two miles wide near Rapid River village and has a nearly flat floor. Two streams flow down it, but without a noticeable height of land between, and each river has a solid rock bottom, (limestone) throughout much of its course. Resting on the rock of the valley floor is an irregular sheet of the ordinary reddish sandy till of the region, usually as it seems from the records of wells, from five to fifteen feet deep, the solid rock beneath being glaciated. There is also a minor quantity of stream deposit of sand and gravel in the valley, but its amount is seemingly insignificant. These features show that the valley is either preglacial or was excavated by the ice which occupied it. Without discussing this question I may state that the first of these hypotheses is probably true. That the valley is not due to post-glacial stream erosion, even to the extent of removing the incoherent deposits left by the ice which last occupied it, is shown by the parallel but independent courses which Rapid and White Fish rivers follow for a distance of about twelve miles, each of them being in a channel from a few inches to three or four feet deep cut in solid rock. This conclusion is apparent from the consideration that if the valley had been cleared of debris by stream erosion, only one main stream would have resulted from the process of stream development that must have obtained.

The most striking features of the valley occupied by Rapid and White Fish rivers, however, is the boldness and the composition of its borders. The escarpment overlooking it both on the east and west is made by slopes of sand which border extensive plateaus. A southward continuation of the bluff on the west forms the conspicuous escarpment of sand which extends from near Rapid River station past Gladstone, to the mouth of Escanaba River, and is present in a modified form, in the western part of Escanaba. The bluff at Gladstone is about 160 feet high, but so far as can be judged from the facts in hand decreases in height when traced northward. The corresponding bluff, on the east side of White Fish River is about 75 feet high. In other words there are two conspicuous escarpments of sand facing each other, with a rock-floored valley between, each sand bluff being the margining escarpment of an extensive sand plain. The sand plains referred to are in each case at least five miles wide in the row of townships (T. 41 N.) crossing the head of Little Bay de Noc, and widen in a conspicuous manner when followed northward. These plains are occupied by open growth of pine and juniper, and are typical "jack-pine plains."

The conditions just described call for an explanation, but as the plains referred to have their chief development to the north of the region examined by me, and pertain more particularly to that section of the state, only a tentative suggestion as to the manner in which they were formed will here be indulged in.

The hypothesis that presents itself in the above connection, is that during the final melting of the former ice sheet which rested on Northern Michigan, a tongue of ice or a narrow ice lobe, lingered in the valley now occupied by Rapid and White Fish rivers and that outwashed sand from the general ice field at the north, accumulated as sand plains along its sides. When the ice tongue finally melted, the sand on its borders was left with steep escarpments facing the depression it left. Stated more briefly, the extensive sand plains bordering the valley of Rapid and White Fish rivers are of the nature of Kame-terraces, as described by R. D. Salisbury[1] and others.

BEACHES OF FORMER LAKES.

Predecessors of the present Great Lakes: One of the most interesting and instructive episodes in the later geological history of North America, for the reason in part that it has an immediate and tangible influence on the commercial and other industries of to-day, relates to the development of the present Great Lakes. As has been shown by the long continued and painstaking investigations of a considerable body of geologists, the Great Lakes have had a varied history and important changes are still in progress.[2]

Previous to the Glacial Epoch, as is judged but not as yet specifically demonstrated, the region occupied by the Great Lakes was well drained and had a maturely developed topography. With each advance of an ice sheet from the north pre-existing conditions were greatly altered, but during each of the several intervals between the ice advances, as has been in part determined, large lakes were probably present. With the final melting back of the ice of the last or Wisconsin stage of glacial occupation, there came a time when the southern margin of the retreating glacier withdrew to the north of the divide separating the streams flowing to the Ohio and Mississippi from the watershed now tributary to the St. Lawrence. The water-parting referred to, is an irregular line, and the southern margin of the retreating ice was also irregular. For these reasons, as the ice melted back, certain portions of the northward sloping land adjacent to the ice became flooded and several small lakes were formed, as for example, at the west end of the Lake Erie basin, the south end of the Lake Michigan basin and the west end of the Lake Superior basin. As the ice withdrew still more to the northward and northeastward, these first formed lakes expanded, and in time united one with another. As successively lower and lower outlets became available, the water of the lakes fell and many changes in their outlines occurred. These changes were controlled mainly by variations in the dam of ice which retained the waters, but movements in the land, of the nature of upheaval and subsidences, also exerted an influence. These earth movements as a whole, tended to tilt the surface of the region in which the basins of the Great Lakes are located; the net result being an elevation of the northeastern portion with reference to the southwest portion.

When the ice had withdrawn sufficiently toward the northeast to leave the entire region now occupied by the Great Lakes to the west of the Ontario basin, free of glaciers, but still lingered in the valley of the St. Lawrence, the Ontario basin discharged its surplus waters by way of the Mohawk

[1] Geological Survey of New Jersey, Vol. V of the final report of the State Geologist, 1902, p. 121.

[2] A popular account of this chapter of geology with the title: "A short history of the Great Lakes," by F. B. Taylor, may be found in Charles R. Dryer's "Studies in Indiana Geography," 1897. Published at Terre Haute, Indiana. The chief first-hand contribution to the literature of the subject may be found in indices to American geology, under the names of E. Desor, Charles Whittlesey, J. W. Spencer, G. K. Gilbert, F. B. Taylor, Frank Leverett, and H. L. Fairchild.

valley into the Hudson. At this time a vast lake named Lake Algonquin, larger than the combined areas of all of the present Great Lakes, flooded the basins of lakes Huron, Michigan and Superior, and overflowed into the Ontario basin by way of the valley of Trent River. Lake Algonquin existed sufficiently long to permit its waves and currents to form well defined gravel terraces and accompanying lake-cliffs about many portions of its border.

A farther withdrawal of the ice which lay on the surface of the present province of Ontario, coupled with movements in the earth's crust, made the Nipissing-Ottawa valley available for the drainage of Lake Algonquin. Its surface was then lowered and it gave place to another lake at a lower level, known as Lake Nipissing. This lake also formed gravel terraces and cliffs about its shores which are stronger and better defined than the similar records left by Lake Algonquin. Lake Nipissing was somewhat smaller than its predecessor, but occupied nearly the entire area now included in lakes Superior, Huron and Michigan, and was larger than the present area of these lakes combined, since its waters were maintained at an horizon about 40 feet above the present elevation of the water in the straits of Mackinac.

The existence of Lake Nipissing was brought to a close by a tilting of the land, which raised its outlet above the level of the channel occupied by St. Clair river, and the present distribution of the Great Lakes was initiated.

Such contributions to the history of the basins of the Great Lakes, as I was able to secure along the northern borders of lakes Huron and Michigan, relate principally to the Algonquin and Nipissing shore-lines and their accompanying gravel and sand deposits.

Topographic Features of Lake Shores: At many localities on lake and ocean shores there is a well defined terrace due to the action of waves and currents in eroding the land. A characteristic cross profile of such a topographic feature is here presented:

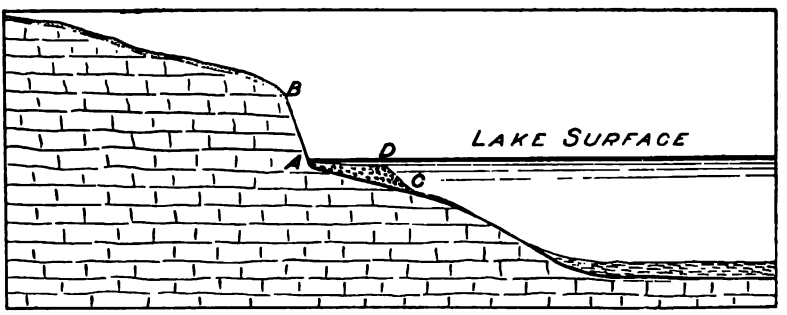


Fig. 5: Cross profile of a lake-cliff and accompanying terrace.

The notch at *a* is due principally to the beating of waves charged with sand and gravel against the land; by this process the cliff *a b* and the cut terrace *a c*, are produced. The deposition of sand and gravel on the cut terrace and extending lakeward, forms a built terrace with a surface inclined downward toward the eroding water-body. When the land bordering a lake slopes gently upward from its margin, and the water deepens gradually lakeward, the destructive action of the waves is less than

under the conditions referred to above, and a lake cliff and its accompanying cut terrace may be obscure or wanting. Under these conditions the pricipal topographic change produced by waves and currents is usually a sand and gravel ridge built in shallow water, parallel with the shore line.

It is by means of these and other similar topographic changes made by the waves and currents of lakes that their former outline can be traced when their waters subside.[1]

The Algonquin Beach: As is indicated on the map forming Plate XVI shore lines made by the waters of Lake Algonquin occur at several localities in the area represented. These are: on the hills about six miles north of Cedarville and Hessel; about the summit portion of Mackinac Island; in the vicinity of Cook's Mills, and again near Ensign, each of these localities being a few miles northward of Big Bay de Noc; about the higher portions of Garden Bluff and Burnt Bluff, on the west side of Garden Peninsula; and a few miles inland from the west shore of Little Bay de Noc and of Green Bay, from the vicinity of Gladstone and Escanaba, southwest to Birch Creek station, about six miles north of Menominee.

At the locality to the north of Cedarville and Hessel there is a group of hills formed principally of Niagara limestone which rise about 300 feet above the present level of Lake Huron. These hills formed two and perhaps three Islands in Lake Algonquin, which have been named by F. B. Taylor, the Munuscong Islands.[2] The waves of the old lake beat on the border of these islands until a well defined beach of coarse gravel was formed about them. A good example of this deposit now excavated for gravel with which to make roads, occurs six miles north of Hessel, where two roads cross at the northwest corner of section 36 T. 43 N., R. 1 W. A fine example of the same ancient lake margin is present about six miles northwest of Hessel near the northwest corner of the township in which that village is located. At the last named locality an extensive view may be obtained of the region to the south and west, which includes the neighboring land and broadly expanded waters of Lake Huron as far as Mackinac Island. With this far reaching landscape in sight, it is easy to fancy the waters of Lake Algonquin restored, and to picture the scene the region formerly presented. At the time referred to, the only land in sight from the Munuscong Islands, in all the vast expanse of water to the south, west and north, was a tiny island formed by the summit portion of the present Mackinac Island. To the northeast, the nearest land was in what is now Ontario to the north of the site of Mud Lake and St. Mary's River. In all other directions the ancient lake extended somewhat farther than do the waters of lakes Superior, Huron and Michigan at the present time.

The elevation of the Algonquin beach about the borders of the former Munuscong Islands is 860 feet above tide and 280 feet above Lake Huron, (The level of Lake Huron being taken as 580 feet.)

The waves as stated above, beat on the margins of the islands for a sufficient length of time to make a well defined gravel beach and the sand washed out from the shore was deposited on the bottom of Lake Algonquin near at hand, and where the water deepened rapidly and especially to the south and west, made extensive accumulations. This apron-like

[1] The changes which lakes make in the topography of the land margining them, has been clearly described by G. K. Gilbert, in an essay entitled "Topographic Features of Lake Shores," in U. S. Geological Survey, 5th Annual Report, 1885, pp. 69–123, see also, "Lakes of North America," by Israel C. Russell published by Ginn & Co., 1895.

[2] American Geologist, Vol. XV, 1895, pp. 24–33.

extension of sand below the old shore still remains and is a conspicuous feature of the low land adjacent to the former islands. Near the northwest corner of the township in which Hessel is located, a well has been dug in this sand to a depth of about ninety feet. The sand about the Munuscong hills becomes gradually thinner, when traced southward but meets the similar deposit made at a lower level by the water of Lake Nipissing, and for these reasons, nearly all the soil of the lowlands to the north of Les Cheneaux Island are sandy.

While the waves were breaking on the borders of the Munuscong Islands and also after the waters of Lake Algonquin subsided, sand was blown over their surfaces from the encircling beach and in places, quite conspicuous sand dunes were produced.

Mackinac Island was much smaller during the existence of Lake Algonquin than at present; the water then stood about 205 feet higher than now on its sides, or 785 feet above tide, according to measurements made by F. B. Taylor and Frank Leverett, and cut a well defined shelf which in places is margined on the landward side by a lake-cliff. At most localities the terrace is covered with water-worn gravel; but in places characteristic gravel beaches are present, without the usual accompaniment of a cut terrace and lake-cliff.

"With the exception of the rocky faces of the great limestone cliffs," as has been well described by Taylor,[1] "which rise on its eastern and western sides, all the lower levels of Mackinac Island show plain evidence of post-glacial submergence. The modern beach is composed almost entirely of limestone pebbles which are generally well rounded. The proportion of crystalline drift material from the north is not great and is confined mainly to bowlders of considerable size. The narrow strip of land upon which the village is built, and which rises to an altitude of 40 to 50 feet at the base of the cliff, is composed entirely of the same characteristic beach material; as may be seen in any of the little gardens of the villagers and in the deep cut back of the Astor house and the old court house. But on ascending to the higher levels of the island the evidence of post-glacial submergence are even more marked. At an altitude of about 170 feet there is a heavy, well developed beach ridge. This ridge is the lowest of a series of four or five like ridges which rise by successive steps to an altitude of about 205 feet above the strait or about 787 feet above sea level. These old beaches may be seen to best advantage on the short target range back of Fort Mackinac. The ground is there cleared of trees and is covered with a short, thick turf, so that the whole series of beach ridges, with their intervening troughs and minor ridges, is admirably exposed to view. At this place the ridges are parallel and comparatively narrow, though strongly developed, and they are also more compactly arranged and more convenient of access than in any other part of the island.

"The short target range crosses the beaches nearly at right angles and the width of the series here is a little less than a quarter of a mile. But on the southwestern side of the island it is three times this width. In some places two or more ridges run together and form one, as is often observed elsewhere. On the short range four heavy ridges are clearly seen with possibly a fifth less distinctly formed. In two of the wider troughs, which

[1] B. F. Taylor, "The highest old shore line on Mackinac Island," in American Journal of Science, Vol. XLIII, 1892, pp. 210–218. In this article the statement is made that the water body termed above Lake Algonquin was an arm of the sea. This view is now held by few if any students of the history of the Great Lakes, and was long since proven to be untenable by Taylor's own investigations.

are five to six feet deep between the main ridges, there are apparently several other little ridges, one or two feet in height. A road which runs parallel to the range and close to its west side cuts the top of each ridge and shows its composition to be a characteristic beach formation. The 205 foot beach is not only the highest one of the series here described, but also the highest on the island. If this ridge be followed through its full extent around the higher ground, it will be found to surround a small tract on three sides. On the remaining side, which is a long, straight line of limestone cliffs facing towards the northeast, all the beach ridges, except the lowest or 170 foot ridge, are wanting. This beach is situated at a considerable distance from the cliff, and the ground between is a broad, level plain with an altitude of 170 to 175 feet. On this plain a heavy talus of fragments and angular limestone bowlders lies against the base of the cliff. While the waves were forming the 205 foot beach around the other sides of the circumscribed tract, they were beating against this northeast cliff and the water on the plain at its base was 30 to 35 feet deep.

"The little island of ancient times, thus defined, was about three-fourths of a mile long and less than half as wide, with its longer axis running about northwest and southeast. Its north end was a sharp promontory formed by the long cliff facing northeast, as just described, and another shorter one facing almost directly west. At the base of the latter the 205 foot beach is well developed, but it is very narrow and the ground drops off rapidly westward to the 170 foot plain. The highest point of the ancient island is at its southern end which forms a rounded promontory and rises to a little less than 100 feet above the 205 foot beach. This point is now crowned by the earthworks of old Fort Holmes, built in 1812, and the descent to the 170 foot plain on the east, and to the 205 foot beach on the south is a steep slope of drift. On its west side, and about a quarter of a mile south of its north point, the surface of the island descends gradually to the 205 foot level. The upper beach is here wide and flat and encloses a considerable tract of low ground behind it."

On the lower portion of the slopes of Mackinac Island, there are other beaches, the Nipissing beach being especially conspicuous, as will be described later.

The hills on the St. Ignace Peninsula rise to a height of about 160 feet above the level of the lakes Huron and Michigan and were completely submerged during the existence of Lake Algonquin, but as the water was drawn off, several islands appeared and at two stages, above the Nipissing horizon, strong well defined beaches were produced.

To the west of St. Ignace in the belt of land adjacent to the north shore of Lake Michigan, the next elevation sufficiently high to stand above the water of Lake Algonquin, is at Cook's Mills on the line of the Minneapolis, St. Paul and Sault Ste. Marie railroad, and near the landward end of the Garden Peninsula. At this locality as determined by Taylor,[1] the Algonquin beach has an elevation of 750 feet above tide, or 168 feet above Lake Michigan. An island or group of small islands existed at this locality during the highest stage of the water in the basins of the Great Lakes and was the first land to the west of Mackinac Island.

The Algonquin beach appears again near Ensign, about 15 miles west of Cook's Mills at an elevation of approximately 700 feet, but this, however, is an indefinite measurement.

[1] F. B. Taylor, "A reconnaissance of the abandoned shore lines of Green Bay," in The American Geologist, Vol. XIII, 1894, pp. 316-327.

On the west side of Garden Peninsula, the coast bordering Big Bay de Noc is bold and rendered picturesque by prominent headlands. From Garden Bay toward the southwest there are several bluffs, the most conspicuous being known in their order from north to south as Garden Bluff, Middle Bluff, and Burnt Bluff, each of which has beach lines about its higher portion. The summit portion of each of these elevations stood as an island in the water of Lake Algonquin. The highest beach on Burnt Bluff, which from its position is identified as a portion of the shore of Lake Algonquin, is 705 feet above tide, or 125 feet above Lake Michigan. The measurements of this elevation by Taylor and myself, by means of aneroid barometers, are identical. Burnt Bluff (Plate XI) is not only the highest elevation in the region about Big Bay de Noc, but is one of the most picturesque localities on the border of the Great Lakes. It resembles Mackinac Island, but presents a steep slope to the northwest instead of southward, and faced the direction from which came the chief ice movement that left striæ on neighboring rock-surfaces. Its summit is covered with glacial drift, proving that like Mackinac Island, it was completely buried beneath ice during at least one and probably during each ice advance of the Glacial epoch. On the bold face of the bluff overlooking Big Bay de Noc, as may be seen from Fayette and other neighboring localities, there are two horizontal lines, due to the presence of cliffs with more or less definite terraces at their bases, which mark the position of the Algonquin and Nipissing shore lines.

As has been recorded by Taylor in the essay referred to above, the Algonquin beach is present on Washington Island, to the south of the southern point of Garden Peninsula and forming a part of the territory of Wisconsin. Other similar islands existed in Lake Algonquin to the southward of Washington Island and were formed by the highest hills on the peninsula and islands of Wisconsin bordering Green Bay on the southeast, thus showing that the present embayment on the northwest shore of Lake Michigan was outlined in part by a belt of small islands in Lake Algonquin.

The shore line of Lake Algonquin has also been identified by Taylor and myself near Gladstone and Escanaba, and thence southwest near the west border of Green Bay, to Birch Creek, about six miles north of Menominee. Its elevation near Escanaba is about 720 feet above tide, or 140 feet above Lake Michigan, but declines when traced southwest to 630 feet above tide or 50 feet above Lake Michigan as determined by Taylor, at Birch Creek. Throughout the portion of the old beach just indicated its position is recorded in part by a gravel ridge, associated in places with a cut terrace and accompanying lake cliff, but principally by the occurrence on its landward side of drumlins and other topographic features due to the action of glaciers, and on the lakeward side by the prevalence of sand which was deposited in the waters of former lakes.

As shown by the measurements of the elevation of the Algonquin beach given above, it is not now horizontal. As the beaches were at least essentially level at the time they were formed, since they record the surface level of a lake, the present departure of their plane from horizontality is evidence of a movement in the portion of the earth's crust beneath. Tabulating the measurements in hand pertaining to the present position of the Algonquin beach, at localities north of and adjacent to the shores of lakes Huron and Michigan, we have:

AN EXCAVATION IN THE NIPISSING BEACH AT ST. IGNACE.
July 6, 1904.

B.—THE NIPISSING BEACH. A CUT TERRACE AND LAKE CLIFF NEAR ST. IGNACE.
July 20, 1904.

Locality.	Elevation above tide determined by aneroid barometer.	Measured by.
Munuscong Islands, to the north of Hessel and Cedarville.	860 feet....	Taylor.
Munuscong Islands, to the north of Hessel and Cedarville.	859 feet....	Russell.
Mackinac Island	785 feet....	Taylor and Leverett.
Mackinac Island	780 feet....	Russell.
Cook's Mills	750 feet....	Taylor.
Ensign	700 feet....	Russell.
Garden Bluff	700 feet....	Russell.
Fayette	710 feet....	Russell.
Burnt Bluff	705 feet....	Taylor.
Burnt Bluff	705 feet....	Russell.
Escanaba River, two miles west of West Gladstone	720 feet....	Russell.
Gladstone	700 feet....	Russell.
Ford River	680 feet....	Russell.
Pine Ridge	690 feet....	Taylor.
Birch Creek	630 feet....	Taylor.

These measurements show an upward inclination of the plane marked out by the waves of Lake Algonquin, from the southwest toward the northeast, at an average rate of approximately two feet to a mile; to the northeast of Mackinac Island, however, the rate increases to about five feet to a mile. Additional observations in this connection made by Taylor, Leverett and others, show that the movement that has occurred since the time of Lake Algonquin, was not of the nature of a regular tilting of the land, but that an irregular upward movement occurred to the northeast of the central part of the former lake. As will be described more fully later, the plane of the Algonquin beach and the plane of a lower, and equally well defined beach in the same region, namely the Nipissing beach, are not parallel and neither of them is now horizontal. That is, earth movements were in progress between the time of Lake Algonquin and of Lake Nipissing and also after the existence of Lake Nipissing.

OLD SHORE-LINES BETWEEN THE ALGONQUIN AND NIPISSING BEACHES.

The outlet of Lake Algonquin as has already been stated, was across the Province of Ontario, by way of the Trent River, and into Lake Iroquois which occupied the basin of the present Lake Ontario. The vast Laurentide ice sheet during the existence of Lake Algonquin, still covered the northeastern part of Ontario, including the valleys of Nipissing and Ottawa rivers. When the margin of the ice melted back so as to leave those valleys uncovered, a lower channel of discharge for Lake Algonquin was rendered available, and its waters were drawn down about 230 feet below their former level. This great change is warrant for giving the lake with a new outlet, an independent name, and it has been christened Lake Nipissing in reference to the river now occupying in part its channel of discharge.

The subsidence of the water from the Algonquin beach to the Nipissing beach was not a continuous process, as beaches strongly defined in certain localities, occur on the sides of the basin these two lakes occupied but intermediate between the beaches they left. On the north side of Mackinac Island, as has been recorded by Taylor, there is a strong well defined gravel beach at the old battlefield now the site of the Wauashkamo Golf Club, known as the Battlefield beach. Its elevation by aneroid is 75 feet above Lake Huron.

A few rods north of the cemetery near the extremity of St. Ignace Penin

sula, there is a well defined beach at an elevation of 84 feet, measured by hand level, above the present level of the water in the Straits of Mackinac. On the hill to the west of St. Ignace near the public school building as recorded by Taylor, there is a strong gravel beach with an elevation of about 75 feet above Lake Huron, or at the same horizon as the Battle Field beach on Mackinac Island.

At Escanaba there is a broad lake terrace between the Algonquin and Nipissing beaches, its elevation being about 50 feet above Lake Michigan.

These and other, but less well defined terraces show that the water lingered at perhaps several horizons during the interval between the formation of the Algonquin beach and the Nipissing beach.

THE NIPISSING BEACH.

The waters of Lake Nipissing lingered longer at one horizon than did the waters of Lake Algonquin and formed much more strongly pronounced shore features. The beaches it left are not only conspicuous in the topography about the north shores of lakes Michigan and Huron, but have an important influence on the drainage of the land and hence on its agricultural and other economic uses.

The Nipissing shore line is in most instances marked by a gravel ridge, but in places where the shores of the lake were steep, cut-terraces and lake-cliffs are present. An important accompaniment of this shore line, as is the case of the Algonquin beach, is the presence on its lakeward side of extensive tracts of lake deposited sand. Nearly everywhere between the beach in question and the margins of the present lakes, the land is sandy, and sand dunes are sometimes present. Above the beach and retained by it are several lakes, and numerous swamps, particularly on Bois Blanc Island and about the borders of St. Ignace Peninsula.

Beginning at the east end of the tract of country considered in this report, (see map forming Plate XVI.), and proceeding westward, the chief localities at which the Nipissing beach is well developed are as follows:

The beach is recognizable at many localities about the borders of Drummond Island and also on the mainland at Detour, at which place its elevation as measured with a hand level, is 51 feet above Lake Huron.

On the south side of a drumlin at Cedarville, (the hill conspicuously marked by the presence on its summit of an old church) there is a strongly defined terrace of coarse well worn gravel, about 40 feet above Lake Huron, which judging from its strength and elevation, is no doubt a part of the Nipissing shore line.

About the heads of several of the deep bays adjacent to Les Cheneaux Islands there are stony gravel ridges at about the height at which the beach under consideration should occur. Owing to the density of the vegetation and in part the swampy character of the land, however, these ridges are somewhat difficult to follow. Les Cheneaux Islands have a general elevation of less than 40 feet and seem to have been shoals during the existence of Lake Nipissing. Their surfaces as already stated, have been washed by waves and currents, and the finer portion of the till of which they are composed, removed, and the stones and boulders it contained concentrated at the surface.

Goose Island and the St. Martin Islands are low, and the Nipissing beach is not present on them, unless, perhaps, about the highest portion of the larger St. Martin Island.

About Mackinac Island the Nipissing beach is strongly drawn, except when precipitous cliffs occur. As has been recorded by Taylor,[1] its elevation is 45 feet above Lake Huron. It forms the terrace on which the higher portion of Mackinac village is built, and on which the Grand Hotel stands. The lake-cliff above this portion of the beach is occupied by the block houses of Fort Mackinac. It is present also near British Landing and is continued as a well defined cut-terrace from there eastward across the north end of the island.

On Round Island this same beach again occurs and a part of the lake-cliff rising above it is noticeable in the forest clothing its eastern side.

All about Bois Blanc Island, the Nipissing beach is well developed. Usually it is a broad gravel ridge, with a surface elevation of about 45 feet above the present lake, but in places, as near Bois Blanc village on the north side of the island and again on the east shore, a stony lake-cliff excavated in limestone is present. The small lake near the east end of the island was not visited by the writer, but judging from the reports of persons familiar with it, seems to be on the landward side of Nipissing beach and to owe its existence to this cause. Duncan or Twin Lakes and its neighboring lake to the east, have a surface elevation of about 35 feet above Lake Huron and are on the lakeward side of the Nipissing beach which is well developed in their vicinity. Between these lakes and the present water margin of Lake Huron, there are sand dunes and beach ridges, pertaining to the time since Lake Nipissing existed. The lakes just mentioned are shallow, the general depth being only five or six feet, their bottoms are dark with peaty accumulations and their waters of an amber color on account of vegetable matter in solution.

All about the borders of the St. Ignace Peninsula, the Nipissing beach forms a conspicuous feature. At the entrances of several embayments on the border of the old lake, stony gravel bars were formed which closed their outlets and transformed them into lagoons. Now that the water in the Huron-Michigan basins has fallen below the level of Lake Nipissing, several of the former lagoons have been transformed into lakes. A fine section of a gravel beach at the Nipissing horizon has been exposed in the excavations recently made for railroad ballast, in the northern part of St. Ignace, an illustration of which is presented in Plate X, A. The appearance of the beach near St. Ignace where it is accompanied by a cut terrace, is shown in Plate X, B.

Lake cliffs due to the undercutting of the borders of Lake Nipissing where the land rose precipitously, occur at St. Louis rock, about three miles north of St. Ignace, and again at Gros Point on the west side of the peninsula where for a distance of several miles a broad cut-terrace with bold bluffs on its landward side, overlooks Lake Michigan. Isolated rocks rising from this terrace show where skerries existed at the time the waters of Lake Nipissing beat upon the shore. Much of the beauty of the scenery in the region about Gros Cap, is due to the shore topography of the old lake. At the cemetery near the south end of Point St. Ignace, the Nipissing beach is represented by a well defined gravel terrace at the foot of a steep slope or lake-cliff, and has an elevation above the level of Lake Michigan, of 45 feet, as determined by means of a hand level.

Brevoort Lake is 20 to 25 feet below the level of the Nipissing beach

[1] F. B. Taylor, "The Second Lake Algonquin," in the American Geologist, Vol. XV, 1895, pp. 100–120, 162–179. (By "Second Lake Algonquin" is meant Lake Nipissing.)

which skirts its southeast border. The lake is separated from Lake Michigan by a broad tract of sand dunes, and probably owes its existence to the cutting off of an embayment of the waters in the Michigan basin at a time subsequent to the existence of Lake Nipissing. Its waters adjacent to its south and west shores are shallow, but in its northern portion are reported to have a depth of 180 feet.

From Brevoort Lake westward for a distance of twenty or more miles, the shores of Lake Michigan are bold and the Nipissing beach was not recognized by me while traversing that region, until reaching the vicinity of Point Patterson where it appears at a distance of from three to five miles inland. From near Point Patterson westward nearly to Manistique the beach is represented by a gravel ridge connected at certain localities with a terrace and low lake-cliffs. At White Dale (Sec. 35, T. 41 N., R. 14 W.) the beach is about 40 feet above Lake Michigan. To the south of the beach the country is usually sandy and in part occupied by dunes, while the lower portions are swampy. Several small lakes below the level of the Nipissing beach owe their existence to beach ridges formed at a later date, or to the accumulation of sand dunes. About the borders of Garden Peninsula the beach is present, and at Burnt Bluff and other localities on the bold shore overlooking Big Bay de Noc, is usually a cut-terrace; but in the valleys leading inland from the heads of the present coves and bays and generally (as is reported) on the low eastern border of the peninsula, it is a sand and gravel ridge. Its elevation at Garden Bay and Burnt Bluff as determined by means of a hand level, is 30 feet above Lake Michigan. As has been recorded by Taylor,[1] "the Nipissing beach has been identified around the northern shore of Green Bay, but was not found to the south of Escanaba. It is the wide flat upon which the higher parts of the towns of Gladstone and Escanaba are built. Back of the former place its upper mark is strong and plain against the foot of a high bluff."

At the mouth of Escanaba River there is a well defined gravel terrace with an elevation of 24 feet above the level of Lake Michigan, and at Farmer's Dock on the east side of Little Bay de Noc, opposite Escanaba, there is a cut-terrace in limestone which records a water level 23 to 24 feet above the same datum[2]

These old shore features are associated with similar records at both higher and lower horizon and their assignment to the Nipissing stage in the history of the Great Lakes basin is based on their relative strength in comparison with the beaches most nearly related to them, and on the conclusion derived from additional evidence by Taylor and others, as to the position the Nipissing beach should occupy in the Escanaba region.

The measurement of the present height of the Nipissing beach given on the past few pages, shows that it declines from 51 feet above the level of lakes Huron and Michigan at Detour, to 45 feet at Mackinac Island and St. Ignace, 30 feet at Garden and Burnt Bluff and 24 feet at Escanaba. The rate of this inclination as determined by Taylor, from a wider range of observation than is indicated above, is 6¼ inches per mile.

The planes of both the Algonquin and the Nipissing beaches, in the region about the north shore of Lake Michigan, as stated above, are inclined downward from the northeast toward the southwest, the former at the rate

[1] F. B. Taylor, "The Second Lake Algonquin," in The American Geologist Vol. XV, 1895, pp. 106-107.

[2] The height of the Nipissing beach at Gladstone and Fayette is given by Taylor as 20 feet. American Geologist, Vol. XV, 1895, p. 118.

BURNT BLUFF–GARDEN PENINSULA, LOOKING SOUTHEAST.

August 13, 1904.

of about two feet per mile and the latter 6½ inches per mile. At these rates of inclination the two beaches should coincide in the region about Menominee. The country on the west side of Green Bay between Escanaba and Menominee, for a distance of five or six miles inland, is low, sandy and swamps and covered with dense vegetation. It has not been examined in detail and only the position of the highest beach present and that at only a few localities, has been well determined. Precisely at what locality the two beaches referred to came together is not known.

To the south of Menominee, the Nipissing beach as represented on a map published by Taylor, passes below the level of Lake Michigan, but observations made by Frank Leverett, as yet only in part recorded, seem to indicate that more tilting has occurred to the northward of a northwest and southeast line drawn through Lake St. Clair and the vicinity of Menominee, than to the south of such a line, and that the Algonquin and Nipissing beaches coincide in the southern half of the Lake Michigan basin, their combined records being a well defined beach about 15 feet above the present water level.

The portion of the glacial and post-glacial history of the basins of the Great Lakes outlined in these pages, although serving to explain many phases of the relief of the region here described, pertains to the changes a very much larger region has experienced, the complete records and full significance of which cannot be discussed at this time. A good summary of the changes referred to may be found in a chapter by Taylor, in Dryer's "Studies in Indiana Geography," to which the reader is referred for additional information.[1]

LAKE CLAYS.

At two localities in the portion of Michigan embraced in this report, one near Hessel, and the other in the region about Isabella, to the north of Big Bay de Noc, there are deposits of fine, pink, thinly laminated, highly plastic clay which as shown by its fineness and evenness of bedding was laid down in a large water body. Similar clay is perhaps present at other localities in the same general region, concealed beneath later deposits of sand and possibly of till, but evidence in this connection is at present wanting.

The clay deposit referred to near Hessel, is located about one mile north of the village in a depression between two drumlins. Its known area is only a few acres, and its depth not ascertained. At Isabella and in the region to the north of that village for a distance as reported by residents, of five or six miles, pink clay is well exposed in the sides of stream and rill channels, and evidently has a thickness as indicated by wells, of at least 50 to 75 feet, but probably exceeds these measures. All about the border of this clay area there is sand in part in the form of dunes, as about Moss Lake, but the clay extends under the sand at least to the westward, as may be seen at many localities in the banks of Sturgeon River.

The clay deposit at Isabella is favorably situated for commercial purposes and as indicated by its fineness, plasticity, general freedom from coarse sand, concretions, etc. is well worth experimenting with for the purpose of ascertaining if it will serve for brick making. An analysis of the clay is as follows:

[1] C. R. Dryer, "Studies in Indiana Geography," Inland Publishing Co., Terre Haute, Indiana, 1897, pp. 90-100.

ANALYSIS OF CLAY FROM ISABELLA.

Analyzed by F. K. Ovitz.

	Per cent.
Silica, S_2O_2	52.81
Aluminum oxide, Al_2O_3	15.66
Ferric oxide, Fe_2O_3	4.91
Calcium oxide, CaO	8.54
Magnesium oxide, MgO	3.16
Phosphoric anhydride, P_2O_5	.12
Sulphuric anhydride, SO	.11
Manganous oxide, MnO	.28
Sodium oxide, Ma_2O	1.34
Potassium oxide, K_2O	3.72
Loss on ignition	10.18
	100.63

The deposits of clay briefly described above, are of the same character as much larger deposits exposed near Sault Ste. Marie and occurring widely on the Lake Superior shore of Michigan. Judging from the pronounced physical characteristics of the clay at these several localities and its known relation to other and associated deposits, it seems evident that it was laid down in a single widely extended water body. No fossils have been found in it to show whether it is of marine or lacustrine origin, but the presumption is that it was deposited in a lake. As to the date at which this lake existed no good evidence has as yet been obtained in Northern Michigan, but during the past summer similar clay previously known to exist in the northern portion of southern Michigan, has been shown by Frank Leverett to be several hundred feet thick and of older date than the surface morainal deposits of the region and to rest upon older glacial deposits. It is thus shown to have been deposited previous to the southward advance of the Wisconsin ice sheet. This is a highly instructive discovery, and if as now seems probable, the pink clays of Northern Michigan were deposited in the same lake as the similar clays in Southern Michigan, the existence of an inter-glacial lake in the Great Lakes basin of comparable size with Lake Algonquin is made manifest.

SAND DUNES.

General characteristics: Sand blown by the wind is frequently deposited in piles, forming conspicuous hills, in much the same manner that snow is blown into drifts. Sand, however, is sometimes piled up at the same locality during a succession of years and the hills formed are in many instances far larger and more conspicuous than the snow drifts that are formed on the lowlands of temperate regions.

One source of supply of sand available for wind transportation, is along lake shores where it is left on the land by waves generated during storms. When sand thus left becomes dry it is blown about by the wind, and on-shore winds frequently drift it inland and pile it in conspicuous heaps. The localities of annual accumulation are usually determined by the presence of vegetation, and to induce conspicuous deposition the plants which assist in the progress of accumulation must be capable of growing from year to year, with comparatively little moisture. Drifts started in this manner are usually elongated in the direction the prevailing winds travel, but when a considerable elevation is produced it causes an eddy in the winds passing over it, and thus leads to additional sand accumulation, which take the form of a snow drift, and an elongated ridge or drift is produced at right

angles to the direction of the carrying winds. Such drifts of sand or *dunes*, have a gentle slope facing the wind which brings the sand and a steep slope in the opposite direction. Sand swept up the gentle slope to the crest of the drift is precipitated over it and the dunes progress as one side is eroded and the other side added to. In this stage the sand drifts are known as *traveling dunes.*

The sand can only be moved by the wind however, when it is dry, and when but little vegetation is growing upon it. In a humid climate like that of Michigan, the prevailing moisture of the sand and the favorable conditions thus produced for the germination of seeds and the growth of vegetation, are factors tending to arrest the advance of sand drifts. When these conditions become dominant the drifts are soon clothed with vegetation, and their progress is arrested. In this condition they are termed *established dunes.*

The drifting of sand inland from a lake shore, is favored to a higher degree on shores facing the prevailing winds of the region where a lake is located, than when these conditions are reversed. The supply of sand is also regulated by currents in lake waters, which tend to carry sand from one part of a lake shore and to deposit it on another part; such localities being determined respectively by the direction of the wind and the nature of the outline of a lake's margin and the topography of its bottom adjacent to the land. Of these and other less conspicuous conditions, which control the movement of sand by lake water, prevailing direction of wind is usually the most important. For example, the winds blowing over Lake Michigan, are prevailingly from the westward and sand dunes are a common and conspicuous feature of its eastern shore, but are practically absent from its western shore. A more complete analysis of the condition favoring the formation of sand dunes about the margins of lakes would include the breadth of the water bodies, and hence the strength of their waves and currents, a broad water body being more favorable in this connection than a narrow one, but perhaps enough has already been said to enable the general reader to appreciate the significance of the facts concerning the sand dunes of Northern Michigan to which attention is invited below:

Dunes on the north shore of Lake Michigan: Nearly the entire area adjacent to lakes Huron and Michigan on the north, is conspicuously sandy. The sand is composed essentially of fragments of quartz, but the solid rocks of the regions are limestone and dolomite, in which sand grains seldom occur, and none of which would yield a conspicuous amount of sand on weathering. The immediate source of the vast quantities of sand mantling the surface and forming the greater part of the soils, as long since pointed out by Desor, is the glacial drift. All of the larger streams of the region especially during their flood stage, bring quantities of sand to the localities where they enter lakes Huron and Michigan, but many of the smaller streams, and even the larger ones during the low-water stages, are clear but of a brownish-yellow color owing to vegetable matter in solution. The clearness of the streams when not in flood, is due to the fact that they are fed at such times by water which filters through sandy deposits, or percolates through the vegetation of swamps.

The waves of the Great Lakes on reaching their shores, as a rule meet deposits of glacial drift, which is eroded, the finer particles being carried lakeward by currents, and the stones and sand dropped near shore in shallow water. This process of washing and assorting the drift has been in operation

from the highest level reached by former water bodies in the basins of lakes Huron and Michigan down to the beaches of the present lakes and throughout this interval sand is abundant. At the various localities where the Algonquin beach is present, sand dunes are more or less prevalent, but as a rule are not conspicuous. Along the Nipissing beach drifted sand is more plentiful than at higher stations, and below that beach and down to the present margins of lakes Huron and Michigan the influence of the wind in forming dunes is frequently well illustrated. The principal dune and the broadest area of wind deposited sand, however, are adjacent to the borders of the present lakes.

Dunes are not a conspicuous feature of the region examined to the east of St. Ignace, although some drifting of the sand which is so abundant in the vicinity of the Nipissing beach, between Hessel and Detour, seems to have occurred. Adjacent to the north shore of Lake Michigan sand is more abundant than about the north shore of Lake Huron, and at several localities has been shaped into characteristic dunes. From near Gros Cap to Brevoort, on the west side of the St. Ignace Peninsula, there is a belt of country adjacent to Lake Michigan and from one to four or five miles wide, which is conspicuous on account of its dune topography. Over much of this region the sand is still drifting, but in large part the hills that have been formed are completely clothed with vegetation, or in other words are established dunes. Many of the dunes are so old that dense forests grow upon them, and before the region was devastated by lumbermen they supported a fine growth of pines.

A characteristic portion of the sand-buried area in question, occurs between Lake Brevoort and Lake Michigan, where there is an extensive tract of undulating and hilly country with marshes and ponds, scantily clothed with vegetation. In this region extensive areas are rendered blue by huckleberries in late summer. Conspicuous dunes rising to a height of 60 to 80 feet, border Brevoort Lake on the west and form the highest land in the vicinity. These hills with deep depressions between, something of the picturesqueness of which is revealed by the photograph forming Plate XII, A, were formerly clothed with pines, and owing to the difficulties of lumbering in such a rough region, some of the aged trees still remain. The dunes are in part washed along their eastern bases by the waters of Lake Brevoort and precipitous slopes imparted to them. The sand removed has in large part been spread out in the lake, shoaling its waters, and along its shore when dry, is again being blown into drifts. Certain portions of the clean washed sand, when dry, gives forth a musical or barking sound when trodden upon, not unlike the sounds emitted by snow beneath one's feet during unusually cold weather.[1]

Sand dunes are also abundant on the blunt peninsula which terminates in Point Patterson, and from there westward to Manistique forming a belt, in general from two to three or four miles wide adjacent to the shore of Lake Michigan. In this region as in the case of the dunes near Brevoort Lake referred to above, the dunes are on the lakeward side of the Nipissing beach. The topography has the usual irregularities of regions of drifted sand and in the hollows swamps are frequent. Owing to the piling up of the sand certain low areas have been isolated and basins produced

[1] Such "barking sand," "singing sands," "musical sand," or "sonorous sand," as it has been termed, occur abundantly in various parts of the world, but the reason for its sound-emitting quality when disturbed has not been explained. At Brevoort Lake the sonorous sand is rather coarse, uniform in grain, and free from fine particles. It is dune sand which has been washed and assorted by the waters of the lake and thrown on the shore, where some drifting has taken place. An abstract of an interesting paper on musical sand, by H. C. Boulton and A. A. Julien may be found in Proceedings, American Association for the Advancement of Science, Vol. XXXIII, 1885, pp. 408–413.

A.—ESTABLISHED DUNES ON WEST SHORE OF BREVOORT LAKE.
August 3, 1904.

B.—EXCAVATION IN A DUNE NEAR MANISTIQUE.
August 10, 1904.

which hold lakes. The region was formerly almost completely forest covered, but the pines have now been cut and fires following the destruction wrought by lumbermen have greatly altered the character of the primitive vegetation. A narrow belt of dunes from 30 to 50 feet high, extends along the shore of Lake Michigan for about two miles, eastward of Manistique. Deforesting has there been complete and the smooth curved surfaces of the sand hills have been converted into pasture land. Near the tops of some of the hills the thin sod has been broken, owing to the trampling of stock, the wind has gained access to the sand beneath the shelter of the grass roots, and has begun to scoop it out. Conspicuous changes from this cause are likely to result. Near Manistique the sand of a dune has been excavated for industrial purposes, and a good section exposed in which the irregular cross bedding, characteristic of wind-deposited material, is well shown. A photograph of this section is presented on Plate XII, B.

A conspicuous feature observed in sections of the dunes near Manistique, and common in many of the sand and till deposits of various kinds throughout the part of Michigan under consideration, is the whiteness of the deposits to a depth of from a few inches to a foot or two below the surface, in comparison with the yellowish or reddish color of the same material at a greater depth. This bleaching of the surface portions of previous deeply colored deposits is due to the removal from them of the iron they previously contained, owing to the solvent power of the downward percolation water charged with acids derived from the decay of vegetation.

Drifted sand covers the surface of the northern portion of the Garden Peninsula, as far south as Portage Bay, and is reported to occur all along its eastern shore. In this region and adjacent to the railroad from Manistique to near the crossing of White Fish River sand dune topography is the prevailing feature of the landscape. Conspicuous dunes occur in the neighborhood of Ensign and also to the north of that village over the jack-pine plains bordering White Fish River on the east.

As previously mentioned, the country from Gladstone to Menominee throughout a belt in general about five miles wide, adjacent to the shore of Green Bay, is deeply sand covered, but conspicuous sand dunes are not known to occur except in the immediate vicinity of Manistique where small examples are conspicuous on account of their barrenness, and also because of the flatness of the country about them. The general lack of dunes in the sandy belt just mentioned, is as it appears, due principally to the fact that the prevailing winds are from the westward and tend to blow the sand that is thrown ashore by waves, lakeward instead of landward.

The dunes to which attention has been directed are instructive chiefly as examples of "established dunes." The regions where sand is now being drifted are restricted in area and confined for the most part to the west side of the St. Ignace Peninsula. At this locality the prevailing westerly winds have the broadest sweep across a lake surface, of any part of the country here considered, but the natural conditions have been greatly modified, owing especially to forest fires. Throughout the whole extent of the north shore of Lake Michigan, the conditions were formerly more favorable than at present for the drifting of sand, and indicates that the dunes preceded the forests. This consideration coupled with what is known of the history of the Great Lakes after the subsidence of the waters of Lake Nipissing, seems to show that when the waters fell from the Nipissing beach

to their present horizon, a sandy region was left exposed and before vegetation became abundant upon it the sand was drifted into dunes. It thus appears as if the now "established dunes" were formed soon after Lake Nipissing subsided, and that the accumulation of drifting sand has gone on at a less rate since that event to the present time.

LAKE AND SWAMP DEPOSITS.

Wet basins: Of later date than the glacial drift and also, in part, subsequent to the formation of the beaches of Lakes Algonquin and Nipissing, and subsequent, also, in many instances to the formation of the established dunes about the northern border of Lake Michigan, are certain deposits made in the many lakes and innumerable marshes and swamps of the region under consideration.

In localities covered with glacial drift at higher elevation than the Algonquin beach, depressions are frequently occupied by lakelets, or swamps. In a similar way, below the Algonquin beach where sand is not abundant, the topography of the drift controls the relief of the surface, and wet depressions are not uncommon; areas of this character are frequent at localities at a distance from the beach, which were deeply submerged during the existence of Lake Algonquin. Illustrations in point are furnished by the numerous lakes and undrained basins on Drummond Island. By far the greater number of the lakes and swamps on the land adjacent to lakes Huron and Michigan on the north, however, occur in association with the Nipissing beach or in the usually sandy tract of country below that beach and extending to the margins of the present Great Lakes.

Deposits: In the wet basins to which attention has just been directed, two classes of deposits have accumulated; one class consists of material brought in suspension by inflowing streams, i. e. mechanically formed; and the other class has been produced by vegetable growths, i. e. organically formed.

Of the mechanical deposits referred to, no more need be said at this time, than that they consist principally of sand.

The organic deposits in the wet basins consist principally of (a) peaty accumulations, due to the growth and decay of many generations of water-loving plants together with leaves etc., blown from the adjacent land, and (b) so-called marl, formed principally by the concentration of lime (calcium carbonate) from lake waters by certain species of algæ.

Peat: The peat deposits are widely distributed throughout the portion of Northern Michigan examined, and occur not only in definite basins but quite generally over the surface of nearly flat and poorly drained land. They seldom reach a great thickness, although in some swampy areas, as about four miles north of Hessel and at certain localities on Drummond Island, they are reported to be 20 to 30 feet deep. In general, however, their depth is measurable in inches rather than feet. In a few instances the peat may perhaps be sufficiently deep and of the requisite physical character to be of economic importance as fuel in the distant future when wood shall have become scarce, but in general it has rather the character of muck or a mucky soil, and is of chief value on account of the fertility it imparts to the sand with which it is usually intimately associated. It is an economically important fact that much of the present swampy condition of Northern Michigan is due to the mat of partially decayed vegetation that rests on the surface and clogs the drainage

channel. The removal of this material from the channels of rills and brooks, and the excavations of shallow ditches would result in rendering sufficiently dry for agricultural purposes, pasturage etc., many extensive tracts which are now dense tamarack and cedar swamps.

Marl: White pulverulent, calcium carbonate resulting from the decay of *Chara* and other fresh water algæ, is present in some of the lakes on Drummond Island and on St. Ignace Peninsula, but so far as has been learned, the amount of such material of sufficient purity to be of value in the manufacture of Portland cement, is not great. More careful exploration in this connection is desirable[1] however, before the absence of commercial quantities of marl can be asserted with entire confidence.

SOILS.

The leading characteristic of the soil of the portion of Northern Michigan considered in this report, is its sandiness, the only conspicuous exceptions being the region occupied by pink clay about Isabella, the surfaces of the washed drumlins in or near Les Cheneaux Island, and the presence over many extensive areas and irrespective of the character of the sub-soil, of muck and other forms of decaying vegetable matter.

The soils of the region indicated on the map forming Plate XVI. with the exception of those composed largely of partially decayed vegetable matter, may be classified so as to indicate this economic importance, in the same manner as the superficial deposits to which they owe their principal characteristics are subdivided. The map just referred to thus becomes a soil map from which in a general way the agricultural possibilities of various areas can be judged. In this connection, it is understood of course, that in addition to the general nature of the soil of a region, other conditions such as its topography, drainage, etc. must be considered as affecting and frequently as exerting the leading control in reference to its agricultural possibilities.

The soil in the portions of the region here considered where till forms the surface are in general reddish, sandy loams.[2] From St. Ignace Peninsula eastward to and including Drummond Island, the till soils which are prevailingly sandy, contain in general a higher percentage of clay-like material than do the similar soils to the north and northwest of Lake Michigan. Examples of till soils without the modifications due to submergence beneath lake waters, in the region lying east of the St. Ignace Peninsula, occur only on the summit portion of Mackinac Island and on the hills to the north of Hessel and Cedarville above the horizon of the Algonquin beach. The former of these localities is only a few score acres in area and is not under cultivation; the latter embraces several square miles, and is favorable for agriculture as is shown by the many fine meadows and grain fields it contains. The soil is a rather stiff loam, except where sand has been blown over it from the Algonquin beach, or muck is in excess as is the case in the poorly drained portions. In general the entire area above the Algonquin beach excepting the wet basins, is favorable for agriculture.

[1]See Reports of the Geological Survey of Michigan, Vol. VIII, Part III, p. 340.

[2]A loam is a mixture of sand and clay in various proportions, together with more or less but in general a small per cent. of organic matter; should any one of these three ingredients be present in excess, and form the leading characteristic of a soil, it may conveniently be termed respectively, a clayey loam which may grade into a clay soil, a sandy loam which may grade into a sandy soil, or mucky or black loam, which may grade into a muck soil. These terms are in common use among farmers and others and are here employed instead of certain more technical classifications of soils that have been proposed.

Below the Algonquin beach on the St. Ignace Peninsula and thence eastward to and including Drummond Island, the till soil, when not concealed beneath subsequently deposited sand, is a reddish loam, but in general contains a notable percentage of sand and grades into decidedly sandy tracts where lake waters have deposited material. Drummond Island, owing to the fact that its site was many miles distant from the nearest land during the existence of Lake Algonquin, is mostly free from lake deposited sand and is covered with a reddish sandy loam of glacial origin. The topography of the central part of the island above the Nipissing beach has an uneven surface and owes its hills and hollows to the irregularities of the till sheet which covers it. The soil is in general fertile and is judged to be suitable for the growing of hay and use for pasture, but only comparatively small portions have been cleared.

Till soils are present in the region about Detour, but a mile or two west of the village sand predominates and extends throughout much of the region adjacent to the north shore of Lake Huron, as far as the low tract of densely forested country about the shores of St. Martin's Bay.

On Les Cheneaux Islands and the hills of the mainland adjacent the soil is till, but as previously explained, much of it has been washed by the waters of lakes and the finer surface material removed leaving the stones and large boulders. The surface is excessively stony (Plate VI, A.) and unsuitable for agriculture, although room for fruit trees might be found among the countless boulders that occupy the surface.

Bois Blanc Island is excessively sandy throughout although the presence of boulders indicates that the surface layer is in part at least a glacial deposit. The sand is usually dark at the surface owing to decaying vegetable matter and when newly cleared and cultivated is said to yield favorable returns, but the vegetable matter soon disappears from cultivated areas, being in part blown away when dry, leaving nearly white sand.

On the St. Ignace Peninsula above the Nipissing beach (45 feet above the surface level of lakes Huron and Michigan) the soil is principally a sandy till. Where the land is sufficiently well drained it is favorable for agriculture as is demonstrated by the prosperous appearance of the farms near Allenville etc. In this region the fertility of the soil is probably enhanced by the presence of gypsum derived from the underlying formations. In the main, however, the soil consists of till brought from the northward by glaciers and not subsequently buried beneath lake deposited sand.

Reddish sandy till soil predominates in the various areas above the Algonquin beach to the west of the St. Ignace Peninsula and especially in Menominee county. The comparatively small area at Cook's Mills and Ensign, which are about the horizon just mentioned, are to a large extent covered with wind deposited sand and are not favorable for agriculture. At Ensign, however, a thin layer of reddish sandy till is present, barely enough to conceal the solid rock beneath, and agriculture has been attempted and more favorable results obtained than the thinness of the soil seems to warrant.

The most favorable agricultural region of considerable extent, throughout the portion of Northern Michigan represented on the map forming Plate XVI., is situated in the drumlin area to the west of Green Bay. This region is higher than the Algonquin beach and the soils on the hills and in some of the valley is a reddish, exceedingly fine sand-loam of glacial origin. As has already been explained the hills throughout Menominee County and

extending into adjacent counties on the north and west, were given their characteristic slopes by ice-erosion during the last advance of glaciers over the region, when the ice melted the fine silt and dust it contained together with a notable but not excessive quantity of stones and boulders was left as a surface sheet over the hills and valleys. To this glacial deposit some æolian dust has probably been added since the melting of the last of the former ice sheets.

The fine surface layer thus superimposed on the land furnishes an excellent soil. In the valleys between the smooth, oval hills, gravel and sand was deposited in many localities by sub-glacial streams, and since the Glacial epoch, peaty soils have been formed in the wet depressions. The drumlins on account of the fine rich soil covering them and also because of the rapid absorption and retention of rain water, and favorable exposures to the sun, offered conditions highly favorable for agriculture. The valleys are more difficult to clear of forest growth and to drain, than are the hills, but yet are by no means beyond redemption.

From an agricultural point of view as well as in reference to mode of origin, the hills and ridges of the Menominee region present two very different types of land forms. The smooth surfaced drumlins with silt-like soils and reddish stony sub-soils, are well suited for agricultural purposes and will no doubt all be cleared and cultivated at an early date; while the eskers or winding ridges of gravel and sand, on account of the extreme porosity of the sub-soil and in general the frequently complete absence of a true soil, other than decaying vegetable matter, are unfavorable for cultivation. While economic interests demand that the drumlins should all be cleared and cultivated, the best use that can be made of the eskers, is, seemingly, to reserve them for wood land, or utilize them for growing fruit. The eskers also furnish an abundant supply of gravel for road-making and other uses.

Below the Algonquin beach and above the Nipissing beach, in the portion of the field lying between the St. Ignace Peninsula and Manistique River, reddish till soils consisting mostly of sandy loam, are present over areas which were sufficiently remote from the shores of the lake which formerly covered them to escape receiving a deposit of lake sand. The areas referred to occur principally between Bovee and Manistique, adjacent to the Minneapolis, St. Paul and Sault Ste. Marie railroad, and on the southern portions of Garden and Bay de Noc Peninsulas. In the region adjacent to the railroad, the till soil over large areas is concealed beneath swamp accumulations, but considerable portions of the region in the neighborhood of Point Patterson, have a favorable slope for drainage, and in fact are drained in part by underground streams flowing through limestone caves and have been cleared for farming purposes. On the Garden Peninsula to the south of the deep sand which covers its northern half, the soil is a reddish sandy loam, with many stones and boulders and in numerous localities when drainage conditions are favorable, is susceptible of a high degree of cultivation. This is a favorable fruit region, and in many ways gives evidence of agricultural prosperity.

On Bay de Noc Peninsula the last ice advance seems to have completely removed all previous surface accumulations, that may have been present, and spread out as it melted, a thin sheet of fine sandy loam, containing loose stones and boulders, in composition much like the surface covering of the drumlins in the Menominee region. The soil layer thus formed is seldom

over three feet thick, and its average depth is in the neighborhood of two feet. It rests on a remarkably even surface of limestone and in spite of its flatness is mostly well drained owing to the presence of fissures in the rock beneath. The soil although thin is of good quality, and a fair advance in agriculture has been made. Below the Nipissing beach as roughly indicated on the map forming Plate. XVI., sand is almost invariably found, and these areas together with their associated sand dunes and the jack-pine sand plains to the north of Bay de Noc Peninsula, cannot be claimed as favorable for cultivation. Their chief value, as it now seems is for the growing of trees.

The most exceptional soils of the region under consideration are those formed from lake clays, as in the region about Isabella (See analysis p. 94.) These are stiff clay soils which in most situations require ditching or other methods of draining, but are productive and give promise of favorable returns when methods of agriculture adapted to their peculiarities are employed. This soil is closely similar to the soil of the large clayey area to the south of Sault Ste. Marie, which is a prosperous agricultural region, and should be equally productive.

In the above brief review of the characteristics of the lands bordering lakes Huron and Michigan on the north, several references have been made to the muck and peat deposits of swamps. On the whole, the soils which owe their leading characteristics to the presence in them of a predominating percentage of decaying vegetable matter are the most common and widely distributed of any of the soil types of the region. The peaty or mucky soils occur not only in wet depressions but in many instances on surfaces which would have a free drainage if the mat of vegetable litter and roots of living plants which occupies the surface were removed. The dense and all but impassable tamarack and cedar swamps for example, which cover extensive areas in Northern Michigan, frequently have a subsoil of sand, and could be drained at comparatively small expense if the land thus rendered available was of sufficient value for farming, but in general these sandy lands, although perhaps productive in hay and grain for a few years after being reclaimed, deteriorate rapidly as the vegetable matter contained in them decays, on account of exposure to the air, and their ultimate value is probably small.

In brief, the two leading types of soil in the region here considered, are sand which grades into sandy loam, and muck which also grades into sand and when drained and exposed to the air is apt to be removed leaving sand or sandy loam. Considering all conditions the region cannot be justly claimed as being even moderately favorable for agriculture, although there are certain conspicuous exceptions as for example, in the drumlin area to the west of Green Bay, on portions of the St. Ignace Peninsula, etc.

RECENT CHANGES OF LAKE SHORES.

In traversing the borders of lakes Huron and Michigan with the charts of the Lake Survey in hand, it becomes apparent that at certain localities conspicuous changes have taken place in the shore lines of the lakes since the surveys on which the charts are based were made. Evidence in this connection has also been obtained from fishermen and others, which shows still more definitely at what time the changes referred to were produced.

The principal changes that have been observed pertain to the formation

of gravel bars between islands, or uniting a former island with the mainland, the building of gravel spits, and the origin of new shoals and islands.

Included in the Lake Survey chart of the Straits of Mackinac, (No. Hd.), based on surveys made—so far as the shore-lines here considered are concerned—in 1851, there are several localities where the present conditions differ from those represented on the chart. The principal instances noted are among Les Cheneaux Islands, (See Plate V.).

White Fish Island as designated on the chart, is now connected with the mainland by a gravel bar, a view of which looking north from the north end of the former island, is presented on Plate XIII, A. The bar has been produced by the junction of two spits; one starting from the island and the other from the end of a cape on the mainland. Fishermen and others familiar with the locality, state that boats with a draught of four feet, passed through the former opening as late as 1889. The pass was closed between 1890 and 1900[1].

Since the surveys referred to above were made, a gravel spit some five hundred feet long, has been formed at the north end of Rover Island. Owing to the unusual height of the water of Lake Huron during the summer of 1904, the spit was submerged at that time with the exception of a few square yards near its lakeward end.

On the chart referred to above, Boot Island is represented as being separated from another and smaller island to the southwest by a narrow strait. This strait is now closed by a gravel bar the surface of which is four or five feet above the present level of Lake Huron.

At the southeast end of La Salle Island a bay is shown on the chart, with a narrow point of land, i. e. a gravel spit, projecting from its southwest shore and nearly dividing it. The spit has been prolonged during recent years, through the action of waves and currents coming principally from the south, and now completely closes the entrance to the inner portion of the former bay, thus transforming it into a lake, from which a small stream outflows to Lake Huron.

The most conspicuous change in the lake shore among Les Cheneaux Islands, is the tying of a small islet known as Penny Isle, to Isle William. The strait between the two formerly independent islands is now crossed by a gravel bar, a portion of which is shown in the photograph forming Plate XIII, B. The bar is in general from ten to twenty feet wide, and rose about two feet above the adjacent water-surface in the summer of 1904. At one locality, however, near its middle, the waves broke across it during storms from the south. The bar consists of two spits which have been extended until they united. One of the spits was built out from Penny Isle towards the northwest and nearly reached Isle William; the other spit was formed by waves and currents coming from the south, which moved gravel and sand along the shore of Isle William, and at present meets the spit projecting from Penny Isle, near its growing end. The sand and gravel swept northwest from Penny Isle, was, as it seems, supplied by material pushed up by ice floes from the surface of the shoal on which the isle is located. The islet itself although indicated on Lake Survey chart No. Hd., and therefore in existence in 1851, is certainly of recent origin, and probably owes its beginning to the concentration of stones and boulders on the surface of a shoal through the action of ice.

[1] For much of the information here presented concerning recent changes of the shore topography among Les Cheneaux Islands, I am indebted to Prof. John R. Allen, of the University of Michigan, who has made several visits to that region.

The process just mentioned, of moving loose stones which rest on the bottom in shallow water and shoving them into piles, is accountable for the appearance from time to time of boulder reefs at various localities about the shores of the Great Lakes. The stones and particularly large boulders, become frozen into the ice which when it breaks and forms floes is moved by the wind and waves; the tendency seems to be to force the greater part of the material thus held, landward, for the reason that in general the on-shore are stronger than the off-shore winds, and also because when open water is present the waves assist in the on-shore movement but not in the reverse movement. The best example of land formed as seems most probable, by this process, is Goose Island, situated about two miles southwest from Marquette Island the largest of "The Snows."

Goose Island is about a mile long, a few rods wide and from 15 to 20 feet high. So far as can be judged it is composed entirely of well worn limestone gravel together with large boulders derived from the glacial drift, and occupies the central part of a shoal. The action of waves and currents in moving the loose material is conspicuous all about its margin, and especially at its north end where the gravel spit shown on Plate XIV, A, has been produced by the meeting of streams of shore drift which travel northward along its sides.

A similar spit with a recurved end, on the south shore of Round Island, is shown in Plate XIV, B.

The most pronounced of the recent changes in shore topography to be recorded at the present time, is at the northwest end of Round Island, a mile south of Mackinac Island, where a gravel spit about a thousand feet long has been formed during the past decade. Two photographs of this locality from nearly the same point of view, one taken in 1885 and the other in 1904, are presented on Plate XV., which indicate quite satisfactorily the nature of the changes that have occurred.

The recent changes in elevation of the surfaces of the Great Lakes have been critically studied by G. K. Gilbert,[1] and the conclusion reached that a movement is taking in the portion of the earth's crust on which the lakes are situated, of the nature of a rise to the northeast or a depression to the southwest. The rate of tilting is about 0.42 foot per hundred miles per century. That is, in the case of a line one hundred miles long, extending in a northeast and southwest direction, and situated in the region of the Great Lakes, the differential movements of its extremities would be 0.42 foot in one hundred years. This change tends to cause a rise of the water on the southwest shores of lakes which have no outlet in that direction, and a shoaling of the water on their northeast shores. From the nature of this change, it is to be expected that the water on the northeast shore of Lake Huron has been falling during the past century, but certain observed conditions appear to furnish an exception to this conclusion.

At Fort Drummond, situated on the southwest shore of Drummond Island, docks supported by cribs filled with stones, were constructed before 1822, and two groups of cribs are still in place. At the more westerly of these two groups, on July 22, 1904, the water was thirty inches above the tops of the upright posts at the corners of the cribs. At the eastern group of cribs on the same date, the water was forty inches deep over the tops of the corner posts. The posts are square at the top, and not abraded as if cut off by moving ice, but have the appearance of having been sawed to a uniform level. The relation of the summits of the posts to water level

[1] U. S. Geological Survey, 18th Annual Report, Part II, pp. 601–647. See also p. 36 of the Report on Huron County, Vol. VIII, Mich. Geol. Survey.

at the time they were put in place, is not known, but a reasonable supposition is that they were above water at that time. Adjacent to the cribs referred to and south of them, i. e. at the lakeward end of the former dock, the water is now seven feet deep. The bases of the chimneys of a former building now designated by the residents of the locality as the Barracks, are now three feet above the water as measured by a hand level.

The facts just recorded indicate that there has been a rise of water of about three feet since the docks at Fort Drummond were built, but the qualifications mentioned, render this conclusion of doubtful value. Possibly a search of the records pertaining to Fort Drummond, would reveal data for determining more accurately than is now practicable to what extent the level of the water has changed since the old fort was built.

The limited time available for the reconnaissance on which the present report is based, did not permit of my making a detailed study of the changes in shore-line topography to which attention has been directed, but it is hoped that the meager data presented, will lead persons who visit Les Cheneaux Islands, Mackinac Island etc., to photograph the localities where the changes are progressing most rapidly and thus secure a record of the alterations in progress.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

A.—RECENT GRAVEL BAR CONNECTING WHITE FISH ISLAND WITH THE MAINLAND.

B.—RECENT GRAVEL BAR CONNECTING PENNY ISLAND WITH ISLE WILLIAM.

DESCRIPTION OF PLATE XIV.

This plate is referred to on page 104 of the text and also illustrates recent changes of shore line. Similar spits have been quite elaborately studied by Gulliver and others.

A. Is a photograph, taken July 16, 1904, of a recent gravel spit at the north end of Goose Island.

B. Is a photograph, taken August 2, 1904, of a recent gravel spit on the southeast shore of Round Island.

A.—RECENT GRAVEL SPIT AT NORTH END OF GOOSE ISLAND.

B.—RECENT GRAVEL SPIT ON SOUTHEAST SHORE OF ROUND ISLAND.
August 2, 1904.

EXPLANATION OF PLATE X.

[illegible] on page 105. The two photographs were taken [illegible] the same direction, at the north- [illegible] Malcolm Island, the bluff on [illegible]. The growth of a thousand feet or spr [illegible].

[illegible] the west coast of Malcolm Island.

Photographed [illegible] May, 1885.

Photographed [illegible] July 17, 1886.

A.—NORTHWEST END OF ROUND ISLAND.

July, 1885.

B.—RECENT GRAVEL SPIT ON NORTHWEST END OF ROUND ISLAND.

July 17, 1904.

DESCRIPT OF PLATE XVI.

This plate is referred to in that on pages 52, 62, 66, 85, 90, 99, 100, 102, and the features of it morev explained.

While it shows primarily the ial deposits, the glacial scratches, and the two most important shore left by former extensions of the Great Lakes system, yet on these in ad way the character of the soil depends, as is more fully explained in tkt from page 99 on, so that it may also be taken as a soil map, except no attempt is made to indicate the smaller areas and peaty deposThe originally swampy areas are shown on old maps issued by the Silsmer Company of Detroit.

SIXTH ANNUAL REPORT

OF THE

STATE GEOLOGIST,

ALFRED C. LANE

TO THE

BOARD OF GEOLOGICAL SURVEY

FOR THE YEAR 1904.

ACCOMPANYING THE PRECEDING PAPERS.

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ILLUSTRATION.

Plate XVII. The Grain of Ophites..... ..... Page 160

ERRATUM.

Page 159, line 18, for "westward" read "eastward."

Office of the State Geologist,
Lansing, Mich., Nov. 14, 1904.

To the Honorable the Board of Geological Survey of the State of Michigan:

Hon. A. T. Bliss, President.
Hon. L. L. Wright.
Hon. Delos Fall, Secretary.

Gentlemen:—

The following is my report for the fiscal year July 1, 1903 to June 30, 1904, and the working season of 1904. I will make it as brief as possible, though there are one or two sub-reports to be included, of some length, since this is the legislative winter, and the State printer is extra busy.

The following is the usual statement of expenses from the annual appropriation:

FINANCES.

	Salary.	Field.	Office.	Total.
July	$352 36	$291 78	$155 53	$799 67
August	425 66	1,320 57	26 60	1,772 43
September	395 66	842 21	47 90	1,285 77
October	243 50	448 58	32 14	724 22
November	300 00	68 33	11 48	379 81
December	306 85	80 16	24 27	411 28
January	299 50	36 00	23 98	359 48
February	234 40	48 00	18 98	301 38
March	444 94	60	24 61	470 15
April	313 80	33 27	11 33	358 40
May	367 98	54 33	153 32	575 63
June	353 14	124 66	83 58	561 38
Total	$4,037 79	$3,348 49	$613 72	$8,000 00

In addition to this we have expended $476.87 for the purchase of the lot upon which your building stands in Houghton, sewerage connections, etc. This expense was due to the fact that the College of Mines upon whose lands our building was placed over ten years ago as tenant at will had grown so that they needed the land, and we had to find a permanent site for this building.

We also had $1,000.00 for continuation of the joint topographic survey with the U. S. G. S. With this and with the help of assistants employed from our annual appropriation, the area adjacent to the Ann Arbor folio on the east down to Detroit river has been covered, and I can lay before you photographs of two thirds of the same. I trust that the whole may be published this winter. Up to Nov. 14, of this there had been expended $861.00.

We have also expended for printing as follows:

Appropriation Sec. 1, Act 231, Session 1901.

		Allotment.
Expended mainly for Volume VIII, Part 3, and annual reports for 1901 and 1902	$1,947.21	$2,800.00
Balance is being used to reprint the Douglas Houghton reports.		

Appropriation Sec. 1, Act 178, Session 1903 per annum.

Allotment for 1903–1904		$1,250.00
Expended for Volume IX and for Annual for 1903 up to Oct. 27	$655.90	
Balance is being used to finish these volumes.		
Available for this report and other printing, 1904–5		$1,250.00

PUBLICATIONS.

In regard to the past year the record has not been as satisfactory as I could have wished. The printing has dragged in an unaccountable way, and Mr. Grimsley's report on Gypsum, which ought to have been out months ago and thus anticipated the present lively interest in the State's extensive resources of this material, is still in the hands of the Robert Smith Printing Co., though I hope it will be out this winter. The same thing is true of the Annual report for 1903-4, which is much larger than I expect this report to be, and contains a number of maps, which are thus tied up from the public.

A certain amount of the material of this report has, however, appeared in the Michigan Miner.

The only item, therefore, for the year 1904, is the issue of the map of the Ann Arbor quadrangle by the U. S. Geological Survey toward the preparation of which we contributed. This may be obtained by writing to the Director of the U. S. Geological Survey, and enclosing five cents for a single copy, or $3.00 per hundred.

WORK IN HAND.

A contour map of Tuscola county is in the engraver's hands, proofs have been revised, and will be inserted in one of the annual reports—that for 1903 if it is not later than this.

A contour map of Bay county has also been prepared, is in the engraver's hands, and is waiting to be inserted in the annual for 1903. The Mss. of W. F. Cooper's report on Bay county is practically ready to start off Volume X of the main series.

In response to many requests we are preparing a large map of the State in nine sheets upon which we can place, not only the bed rock geology, or that of the pre-Pleistocene, but also the surface geology of the glacial and unconsolidated sands, gravels, clays and till, and the soil. To this end arrangements have been made for co-operation with Mr. Frank Leverett, as is stated below:

Both C. A. Davis, who is working for us on peat and Tuscola county, and W. F. Cooper, and W. M. Gregory who is working on Arenac county have been delayed in their work for us by taking up hydrographic investigations for Messrs. Leverett and Fuller of the U. S. Geological Survey.

They received for this work better pay, and were still developing our scientific and economic knowledge of the State without expense to the State.

The information they were gaining will also be a direct help to us in making our reports more complete. Therefore I have felt amply justified in my cordial approval even though it did mean some delay for us.

W. H. Sherzer has practically completed the field work about Wayne county, and is now only waiting for the completion of his base, which will be constructed from the contour maps prepared in co-operation with the U. S. Geological Survey above mentioned.

CO-OPERATION.

As the country grows more closely knit together and the activities of the Federal government expand it becomes more and more necessary to enter into close relations of co-operation with its various departments, if there is not to be wasteful duplication of efforts. The exact researches which can best be handled by the general and local organizations remain to be determined by experiment.

There are great advantages in a uniform method of collecting and treating data throughout the country, and yet there are lines of work which can best be undertaken by one who is in close touch with local conditions, and in any case one who is so in touch can render important services. It has seemed to me that so long as our knowledge of the value of the State was being enlarged it was of comparatively little importance as to whether the State or the nation was the organ through which it was published. Yet it seems to me possible that some of the lines of work undertaken by the Federal government could better be handled by a chief close at hand and in close touch with local conditions. On the other hand tests and laboratory experiments are very well centralized. There is an opportunity for more continuous use of expensive apparatus and closely comparative study. The following is a list from memory of Federal authorities with whom we have been in correspondence and co-operation with some indication of the extent:

U. S. Geological Survey. Topographic division. H. M. Wilson, in charge, Messrs. Cooke, Williamson, and others, employed in joint topographic survey of Detroit quadrangle.

Geological Division. Information furnished H. Ries, and material for tests; information and computations furnished Leverett and I. C. Russell regarding the Ann Arbor folio; map of surface geology of State planned in co-operation with F. Leverett, and Prof. I. C. Russell employed for the summer in connection; joint excursion over the Iron Ranges.

Hydrographic division. Correspondence with R. B. Dole, M. L. Fuller, clippings furnished and maps and information on our files, Cooper, Davis, Gregory and Sherzer spared for special work in regard to wells.

Correspondence with R. E. Horton, assistant Beebe, and others with regard to Lansing gage, records, photographs in connection with stream measurements.

Correspondence and interviews with E. F. Lines and W. C. Alden and clippings and other assistance with regard to deep wells, the Ypsilanti well especially.

U. S. Division of Agriculture. Division of soils, W. E. Hearn and others. Access to soil maps of Bay and Saginaw counties, and contour maps of Bay and Tuscola counties, and sundry other maps.

Division of road inquiry. Material for tests.

As usual a part of our staff of helpers comes from the College of Mines,

others from the University and State Normal College. The arrangement which you have sanctioned[1] that I shall give lectures at the University does not begin until next year.

U. S. Coast and Geodetic Survey. Unpublished maps and reports.

U. S. Department of Engineers. Maps and report.

After a few years more experience I think I shall be able to make some definite suggestions as to the wisest line of demarkation between the Federal and State activities.

In other directions we have tried to maintain friendly relations with those engaged in allied ways,—and have furnished articles as desired to the Michigan Miner,[2] The Gateway,[3] etc., and have presented appropriate results of our work to the Michigan Engineering Society and Academy of Sciences, thus making up in part for delay in issuance of our own reports.

Additional notes on the occurrence and development of a number of materials, upon which we have recently issued special reports, may be appropriately grouped as notes on the development of substitutes for wood.

SUBSTITUTES FOR WOOD—SHALE, CLAY, PLASTER, CEMENT, COAL AND PEAT.

Wood was formerly used in this State for: shelter in shingles, siding, and joists; paving, in corduroy and plank roads and cedar block; and fuel as hardwood, charcoal and slabs. In the first capacity it is becoming replaced by brick of the common kind or paving brick and sand brick, building stone and artificial stone, or concrete block. For paving it is replaced by paving brick, asphalt block, and macadam, especially that form of tar macadam known as bitulithic. For fuel coal, and perhaps peat are assuming greater dominance.

We will take up first clays and shales.

CLAYS AND SHALES.

A number of samples have been sent to this office for examination.

Samples near Petoskey seem to have the properties usual to the Antrim shale,[4] and will probably be a valuable shale. In the northern part of the State near Norwood and Bellaire, there appears to be more green shale or blue shale and less black shale at this horizon. Yet there is some which is still at times taken for coal, or a sign of coal, in spite of my repeated warnings that no coal exists in these regions.[5]

It will be remembered that we have made some tests of the Valley Coal Co. clays (the Dutch Creek Coal Mines is the popular name of the location.)

A small brick plant was started here some years ago. This has recently been extended and enlarged, and the Michigan Vitrified Brick Co. having purchased the mine and the Pierce dry pressed brick plant adjoining has gone into the business of making high grade paving brick.[6] They mine for use 4½ feet of white shale (fire clay) and 6 of shale half and half. A

[1] "That in view of his long service and experience with the Survey and the increase in expenses, and the advantages that such lectures would be to the State University in which the whole state is interested, the State Geologist be permitted to give a course of two lectures per week on Economic Geology at the University, being paid therefor by the University, without deduction from his salary of $2,000 per annum for the year 1904-5.

Provided, however, that expenses incurred in going to Ann Arbor and delivering these lectures shall not be charged against the Survey.

And provided also that one month be deducted from the vacation heretofore allowed him."

[2] December, January, February, March, April, May, and July numbers.

[3] October.

[4] Volume VIII, p. 45. Antrim was formerly called St. Clair.

[5] Petoskey Evening News.

[6] Michigan Investor, 1904, p. 186.

Bonnet No. 4. pug mill and stiff mud machine can turn out 50,000 to 70,000 brick a day, automatically side cut by wire and repressed. They are dried in from 24 to 48 hours in five foot tunnels 126 feet long having a slope of 1 foot in 7, so that the bricks run through in cars by gravity, while in the other direction there is a forced draft by a 180 inch fan using largely the waste heat from the kilns, but 9,000 feet of radiation are provided in case there is not enough waste heat.

Near Omer the Michigan Paving Brick Co.[1] are putting in a modern plant to make shale brick. The shale is exposed along the river bank, the section being:

11 sand and clay, 17½ shale etc.

A bank of white clay suitable for pressed brick[2] is said to have been found on Sec. 20, T. 16, W., R. 1 S. on the bank of the river two miles east of Maple Grove. It is probably a calcareous clay except where it has been leached at the surface.

Two miles south of Union City a bed of 40 or more acres and 80 feet thick, practically of the Coldwater shale, is said to have been discovered, and to be suitable for fire brick and tile. Throughout this region exposures of Coldwater shale are likely to occur, often softened down into clay, and their value we have already remarked.[3]

A number of samples of the common blue surface clays containing a good proportion of dolomitic flour and apparently good for nothing but common brick have been sent.[4]

An important test for paving brick or brick of any kind is the porosity. A rough test I have seen is simply in spattering ink on a brick and seeing how it spreads. An experienced man can form some idea from this of the porosity of a brick. But a much better idea comes from the weight. An absolutely non-porous brick should weigh about 2,600 ounces to the cubic foot, and if we weigh and estimate the dimensions of a brick, finding what its weight is per cubic foot, we may estimate that what it falls short of 2,600 is to 2,600 as is the pore space in per cent. of volume.

Besides paving brick there are new factories of common brick to be made from the surface clay going up continually from time to time at appropriate places. Concerning these pink clays which also occur abundantly north of Bessemer and at other points, see Prof. Russell's report and that on Bessemer and Black River.

SAND BRICK.

Another important industry is that of making sand brick. There are a number of factories under slightly differing patents. The essential feature of all these brick is that they are made of sand and a little slacked lime, which are mixed, with coloring matter if desired, pressed and steamed. Two plants are working at Saginaw, and there are others at Holland, in connection with the Sibley quarry at Trenton, etc.[5]

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[1] Detroit News, 4:27: 1904.
[2] South Haven Tribune, 4-25-1904.
[3] Quincy News, 8: 19: 1904; Detroit News, 8-16-1904.
[4] May 11.
[5] Also near Michigan City and Jackson. See annual report for 1903. An important series of articles by S. V. Peppel are running in the Clay Record and in the Statistics of the Clay Working Industries of the U. S. in 1903, (curious places, for there is practically no clay in the brick). He says that the best grades of sandlime brick having crushing strengths of 5,000 pounds or more per square inch will absorb 8 to 11% of their weight and has known some with 14 to 15% absorption. One sample which I tested from a new location has 12.3 % ratio of absorption, specific weight 2.64. I understand that one of the difficult points of manufacture is to get sufficient compression.
A sand making a spotted brick which was sent me to see what was the matter, though I rather liked the color effect, proved to be pyritic. I have seen a number of Michigan brick very nicely colored.

Another form of brick is made with cement, but generally speaking when cement is used larger forms are employed, and concrete block. Wherever there is good gravel is a suitable place for the manufacture of concrete block. The particular gravel to be sought is one that while freed from clay has otherwise a good variety in the size of its particles.[1]

The test is to see how much water can be absorbed in the voids. In the samples tested by Pierson it was from 25% to 23% and the average weight of the sand and gravel particles (specific gravity) was about 2,650 ounces per cubic foot. As with brick the shortage of weight per cubic foot indicates the porosity. The various brands of Michigan Portland cement are used in making this concrete block at very low prices.

CEMENT.

The year has been one of severe competition in the cement business and that has not favored the exploration of new deposits. G. W. Berger[2] has furnished us maps and plans of the Lakelands deposits which will be of interest perhaps later in showing the rate of growth of such deposits and of filling of marl lakes. Tallman Lake, Mason county, is said to have 15 feet of bog lime. Round Lake, Mason county, is said to have 20 feet of bog lime.[3]

Work has been done southwest of Manchester, Mich., where the Toledo Portland Cement Co. has 500 acres of beds of bog lime from 12 to 60 feet deep around Wampler's, Iron Creek Mill Pond, Louise Lake, Half Moon, Black and Mud Lakes. They have 300 acres also of the ordinary surface clay. The White Portland Cement Company have erected a kiln plant at Four-mile Lake in Washtenaw county.

Hancock and Calumet people are planning to use waste stamp sand from the copper mines for concrete building block.[4] It must not be forgotten that for such purposes the crushed conglomerate is likely to prove far more durable than the crushed amygdaloid. The Franklin Junior (formerly Albany and Boston, and Peninsular), the Allouez (old mine), the Calumet and the Tamarack are the mines which have used conglomerate rock to any great extent.

L. L. Kimball prepared for the U. S. Geological Survey a report on Portland cement in Michigan in 1903. He reports ten companies using "marl" or boglime and three limestone. The quality of the cement, unless it is put out too green, is almost uniformly excellent. The critical thing for the plants using boglime is the cost of drying. "The problem of utilizing waste heat to dry the marl is one that engages the attention." In addition to water if there is much organic matter, and there is likely always to be some calcium succinate as Davis has shown, it may be impossible to make a profit, for the output will be too small.[5]

Limestone avoids this cost and if not too hard and if low in magnesia will probably be found more suitable. Certain beds in the Traverse are well suited. These strata occupy the north part of the peninsula from Alpena to Charlevoix and the Alpena and Elk Rapids plants use limestone. A plant has also been talked of near Rogers City.

In addition to the data which I have given in previous reports, we may

[1] See Michigan Engineer for 1904, p. 126, article by Geo. S. Pierson.
[2] See sixth report Michigan Academy of Sciences.
[3] Ludington Record, October 6, 1904.
[4] Marquette Mining Journal, Apr. 30, 1904.
[5] See Hale's remarks, pp. 167-168, Vol. VIII, Part II.

include extracts from the following report which we owe to the kindness of Mr. F. D. Larke.

REPORT OF A. UDDENBERG ON LIMESTONE NEAR ROGERS CITY.

Fred Denny Larke, et. al.
Rogers City Michigan.

Gentlemen:—

I hereby submit the following report based on the examinations made by me[1] on the region lying west of Rogers City in Presque Isle county, Michigan.

As to the geology of the country, only a very short description can be given, taking in consideration the time allowed for such examinations and the few outcrops and sinkholes from where any studies could be made.

The whole formation in the country examined is a limestone formation, with but a subordinate development of shaly beds belonging to the Hamilton group of limestones. The thickness of the formation could not be ascertained., but it is in all probability several hundred feet. As to the extent, it goes through the whole peninsula to the shore of Lake Michigan appearing in ridges, in many places cut off by ravines. The country seems to consist of several terraces but though, on many places, one might by a hasty judgment think there is no rock, one will almost surely find the same rock formation when digging down.

The mass of rock is a fine grained pure limestone of a sometimes bluish gray color sometimes a little darker or lighter with interstratified seams of shales which are black or dark gray and very rich in fossils. It contains streaks or seams of a nearly white crystalline limestone all over sprinkled with very fine specks of iron pyrites. The rock is covered by a more or less considerable coating of drift material, consisting of a gravelly loam of a very fertile nature, making it very good for farming purposes.

It was thought that the iron pyrites found in this rock would carry some gold or silver, but in the numerous samples collected by me and assays thereon, it is clearly shown that these precious metals are not to be found in said pyrites. Anyhow there is not pyrites of sufficient quantity to warrant any exploring for said metals even if traces of silver should be found which is not probable. I found several boulders on the surface richer in pyrites which may carry some gold or silver, but as they do not belong to the formation, but are carried there by moraines, they are of no value.

Some of the limestones seem to appear in pretty solid blocks, as could be seen in an exploring pit on Ritzler's farm and it is supposed that said stones would make a marble. Specimens of marble have been taken out and polished and they had a splendid appearance, fully showing the great number of fossils that this formation contains. The specimens collected by me and polished at the marble works in this city do not show up as good. It is true that the stone shows the fossils very nice, but it takes polish very uneven, depending on that some parts are harder and some looser, whereby these different parts take more or less polish and making the cost of this work higher.

The question is also, if in going down the blocks hold out to be solid or

[1] From the shale at Crawford's quarry and from Roger's City, 2½ miles back at each place, and also two miles west of Rogers City.

if they are more or less shattered. I hardly believe that the rock has the compactness and homogeneous qualities requisite for marble.

To find out if this limestone was suitable for manufacture of cement analysis was made by me and is as follows:

Carbonate of lime	97.83
Carbonate of magnesia	1.29
Sulph. of iron	.49
Organic matter	.39
	100.00

As it is necessary for making cement that the rock contains silica, not less than 10%, this limestone will not do for making cement,[1] but will make an excellent white quick slaking lime, which in combination with the clay found in the drift formation and which furnishes an excellent material for brick manufacturers ought to be opened up and would, I am sure, become a paying business employing a great number of men and thereby build up quite a large city. With the railroad facilities that will soon be at Rogers City, when there will be communications the year around and also a market, it cannot fail. As to the cost of taking out the rock for any purposes it will be very cheap if it is managed right. The best way is to strip the surface so as to get at a large space of the rock and work it from top as much as possible, thereby getting rid of the water, which would be of great trouble when working in shafts and thereby go down deep encountering more water.

The cost of taking out this rock if worked as a quarry and for manufacture of lime would not exceed 50c a ton.

Respectfully yours,
(Signed) ARTHUR UDDENBERG.

Marquette, Mich., Nov. 10, 1888.

Judging from the analysis the rock would be suitable for chemical work (beet sugar and soda manufacture) and to mix with shale for Portland cement.

Dr. Grabau is still working up the limestones of this district from an economic as well as paleontologic point of view, and I hoped to be able to present a few plates of fossils herewith.

We have no new data to add in regard to building stones or slate. Dr. H. Ries of Cornell is making some tests of the fire resisting powers of some stones.

In regard to road metal uses we would call especial attention to the papers and discussion in the 1904 Michigan Engineer. A good deal of paving has been done this year, and paving brick and bitulithic macadam appear to be widely favored.

PEAT.

In another direction wood is being replaced and that is by fuels. The Capac plant for peat manufacture seems not to have been a success. The Bancroft and Chelsea plants are now producing some fuel[2] and others are in contemplation. Prof. C. A. Davis and others are continuing researches for me at Ann Arbor.

[1] Except for grinding with clay shale, in which case it would make excellent Portland cement.
[2] Detroit Free Press, April 13, 1904.

The main results appear to be:

1. The different kinds of peat so called are largely only different stages in the development of a peat bog and its decay.

2. A good plastic peat is likely to be more workable and acceptable even holding somewhat more clay (ash), than one which retains too much of the sedge fibre.

3. A peat may take up as much as 15% moisture from the air after being thoroughly dried, as the figurcs below show. While therefore it is likely that when compressed this action will be slow, it is doubtful if it is worth while to reduce the moisture below 15% unless it is to be actually coked, and fuel gas made.[1]

PEAT TESTS BY L. KIRSCHBRAUM.

University laboratory of Prof. E. D. Campbell, Ann Arbor, Mich., May 17, 1904.

No.	Peat.	Sample wet.	Dried.	Wt. Dried.	Moisture.
1.	Jackson Bog I	5.0036 gr.	100–110°	.7339	85.33 %
2.	Jackson Bog I	5.1971	Over H_2So_4	.7709	85 17
3.	Jackson Bog I	5.1447	150° C	.7213	85 98
4.	Capac Peat Co	4.7013	100–110°	.5175	88 99
5.	Capac Peat Co	4.7350	$H_2 So_4$	.5081	89.25
6.	Capac Peat Co	5.9224	150° C.	.5418	90.86

No.	Exposure.	Wt. after 12 hours.	% gain.	24 hours.	% gain.	36 hours.	% gain.	48 hours.	% gain.	72 hours.
1.	Sat. Atm. 34° C.	.....	.....	.7811	6.43?	.....	.....	.7832	6.73	.....
*2.	Sat. Atm. 19–26°	.....	.....	.8817	14.34?	.....	.....	.9127	18.93	.8848
3.	Open air	.8099	12.28	.8296	15.01	.8163	13.17?	.....	.....	.....
4.	Sat Atm. 34° C.	.....	.....	.5399	4.37?	.....	.....	.5409	4.50	.....
*5.	Sat. Atm. 19–26	.....	.....	.5606	10.33	.....	.....	.5740	12.96	.5605
6.	Open air	.5821	7.44	.5977	10.32	.5814	7.31	.....	.....	.....

3 and 6 were exposed during a rain storm between 12 and 24 hours.
*%Gain 72 hours. No. 2. 14.77. No. 5. 10.33.

MORENCI PEAT.

June 14, 1904.

"I enclose a report of test of peat from Morenci, Mich. This sample was recently submitted to us by Prof. Davis, and was tested in a saturated atmosphere at room temperature. This held fairly constant during the day at 21 degrees C., but at night probably fell off some."

Sample wet.—5.05069. Loss wt.—3.7010. Moisture—73.28%. Dried sample.—1.3496.

Exposed in Sat. Atm. at room temperature.	12 hrs.	24 hrs.	36 hrs.	48 hrs.	84 hrs.
Gain	.1770	.1752	.2000	.2058	.2020
Per cent	13.11	12.98	14.82	15.25	14.98

L. KIRSCHBRAUM.

[1] Some remarkable success in this direction is reported from Prof. Norton of the Mass. Institute of Technology.

PEAT ANALYSES.

From letter October 3, 1903.

	Capac pressed.	Capac air dried.	Jackson.	Bronson.	Bronson.
Moisture	14.54	12.32	14.59	12.95	11.90
Volatile Comb	62.48	64.96	54.62	60.81	62.95
Fixed Carbon	17.90	19.93	15.60	16.32	18.16
Ash	5.08	2.79	15.19	9.92	6.99
Sum	100.000	100.000	100.000	100.000	100.000
Total S	.08	.07	.63	.78	.76
Iron	.50	.39	.51	.35	.49
Heating Power	47.00	49.75	41.00	45.50	49.50

E. E. WARE.

During the summer I had a chance to visit Lexington, an early home of the peat industry. I found a cousin of mine had an old fashioned slane, or peat cutting spade, and Dr. G. C. Jenkins was at work there making peat rolls as they may be called.

He said that he had had experience abroad in manufacturing them and found that for grates considerable attractiveness was added by mixing a little salt or copper sulphates to produce colored flames.

COAL.

The other substitute for wood is coal. Much information regarding the development of our coal field can be found in the quarterly bulletins of the Commissioner of Labor.

Some of the more important features geologically are the extension of the area and depth explored, mainly in Bay county.

The new Foss shaft,[1] the What Cheer Mine, in Merritt township is 206 feet deep, 96 feet to rock. It was sunk 103 feet in 15 days, by W. E. Williams, and between that and 173 feet struck, it is said, eight distinct seams of coal, the main coal seam to which they are sinking, a Saginaw seam, being at 200 feet. It is beyond question that a large part of the early coal drilling was not deep enough to prove that coal did not underlie the land, the holes not passing through the coal formation. This shaft was fortunate in not finding much water gravel, a formation it is well to avoid in sinking a shaft.

The Auburn Coal Co.[2] shaft, 200 yards north of the Auburn road, about 7 miles from Bay City, 620 feet from the railroad, had much more difficulty. The first 50 feet was clay from 18 to 40 feet stony, then below at 50 feet a smooth brown interglacial clay then to 84 feet was a heavy bed of sand and gravel with a big stone at 70 feet, and a large flow of water (50° F. or 52° F. at pump). The total depth to bed rock was 91 feet. It took some two months to get through the water gravel. Within the city limits are the United City Coal Co.[3] shaft and that of the Cass River Coal

[1] Bay City Tribune, July 27, 28, Aug. 14, Aug. 21. Started July 9, 113 feet July 27, 175 feet Aug 14, finished Aug. 21.
[2] Bay City Tribune, June 9, 1904; Aug. 3, 1904.
[3] Detroit Free Press, Aug. 27, 1904; June 23, 1904.

Co.[1] The former is in West Bay City near N. Union street, and between Center street and Williams street, occupied by the R. R. This had a till clay almost from the start, and as is so usual with the Verne coal is said to have a two foot seam separated by a foot of shale. The latter is in East Saginaw, at the south end near the water works, and the 136 feet is said to have been accomplished in 28 days working time. This is an extension of the field of the Standard, Saginaw, and Pere Marquette No. 1. A section of the seam is:

12 inches, coal and slate high in ash.
19 inches, coal, clean and bright, no sulphur.
5 inches, some sulphur and slate and rush impressions.

As to the quality of the Bay county coal, the following analyses are of interest, which indicate that as stated in my coal report the Bay county seams are mainly the Verne seams.

BAY COUNTY COAL ANALYSES.

Number	1	2	3	4	5
Location	Wolverine. 3	Wolverine. 2	Wolverine. 2	Wolverine. 2 pt.	Salzburg.
Moisture	4.14	6.18	6.76	8.92	6.50
Volatile Comb	45.70	46.10	42.67	36.49	43.61
Fixed Carbon	42.14	40.88	42.01	51.92	47.82
Ash	8.02	6.84	8.65	2.67	2.07
Sum	100.000	100.000	100.000	100.000	100.000
Total S	3.53	2.27	3.50	1.49	.89
S from Fe	(3.77)	(2.59)	.....	.....	.....
Iron	3.30	2.54	.....	.....	.....
Fe_2O_3	(4.72)	(3.63)	.....	.....	.....
Clay (Ash–Fe_2O_3)	3.30	3.21	.....	.....	.....
Pyrite	7.07	5.13	.....	.....	.....
Combustible Matter	87.84	86.98	84.68	88.41	91.43
Ratio of fixed Carbon and combustible	.48	.47	.497	.587	.523
Heating Power B. T. U	12,520	13,335	12,295	.....	.....
Calculated Lane	13,871	13,690	13,390	.....	.....

[2] Is iron present as carbonate?
Numbers in parentheses are calculated.

1. From H. M. Randall for Handy Bros., by Dickman and McKenzie.
2. From H. M. Randall.
3. Dickman and McKenzie for Wickes Bros., carload dried at 100 C.
4. L. Kirschbraum, part of Wolverine No. 2 seam supposed to be cannel but not very good.
5. L. Kirschbraum, Salzburg mine.

Coal exploration is spreading to the northern part of Bay county and over into Midland[2] and Gladwin counties. Coal undoubtedly exists, but how much of value remains to be seen. In the forthcoming Bay county report a large number of records are compiled. It is a question whether the present exploring is always deep enough. In this connection the following is of interest:

[1] Saginaw Courier-Herald, Sept. 2, 1904.
[2] Gladwin Record, Aug. 5, 1904. Geneva and Larkin townships. Saginaw News, Sept. 26, 1904.

RECORDS FOR THE BORINGS FOR COAL ON THE PENINSULA COAL AND SALT COMPANY'S LAND AND VICINITY.

(As taken from the Bay City Tribune under dates April 1, 10, and 13, May 11 and 13, and June 30, at the time the tests were made.)

The first hole bored was to a depth of 120 feet, and while a vein of only 6 inches in depth was struck and the miners discovered vast quantities of slate and fire clay, which by many is supposed to be as great a source of wealth as the coal. We sub-join a statement of the thickness of the different veins:

Surface clay	12 ft.	Black slate	4½ ft.
Sand and rock	30 ft.	Coal	½ ft.
Light gray slate	7 ft.	Fire clay	1½ ft.
Dark gray slate	3½ ft.	Light shale	8½ ft.
Light slate	3 ft.	Black slate	4½ ft.
Fire clay	4½ ft.	Light gray slate	3 ft.
Gray slate	3 ft.	Black slate	13 ft.
Black slate	7 ft.	Light slate	6 ft.
Fire clay	5 ft.		

And below this something that is supposed to be lead.

After shifting from the first hole struck a vein of coal only 11 feet below the surface, continuing the vein the boring was found to be 2½ feet in thickness, below it five feet of slate was found and under this another vein of coal 5 feet in thickness. This is thicker than the average vein and taken in connection with the one 2½ feet just above would return large profits by mining twice as far below the surface. This is only 28 feet from the top of the ground. Its value is double because of the ease with which it can be mined.

April 13, 1875, telegram from E. G. Sovereign from Sterling that they had struck a vein of 6 feet in thickness. This is the fourth hole bored. In the first hole 6 inches of coal was struck, in the second 18 inches, in the third hole 5 feet, and 2½ feet respectively in the last 6 feet. The latter vein is 19 feet below the surface. There being above the coal 18 feet of clay and 9 feet of slate.

It has already been stated that there exists a vein of 7½ feet of coal of excellent quality within 25 feet of the surface. The company have nearly 3,000 acres.

On May 10th E. G. Sovereign came down from the Rifle River and reported that the shaft is down four feet into the 7 foot vein. The miners are taking out large quantities of the black diamonds and have already taken out 15 tons. Mr. James F. Joy president of the Michigan Central, telegraphed that he would give an excursion to the mines. May 13, excursion to Rifle River. Explorations made by business men and persons from abroad. Successful tests of the coal in grates and forges. On this excursion a special train was sent and 100 persons availed themselves of the opportunity. Left Bay City a little before 2 and arrived at Sterling at 9:15. There were 90 passengers found teams and the balance walked over to the mine. The mine was kept running until June 30th.

I sent to Capt. R. M. Burlington three tons of the coal to try on his steam

tug. I herewith enclose you a paragraph of his letter, in answer to the same. "We burned the sample of coal, giving it a fair test and find it all right. It burns up cleanly and makes good steam, no clinkers. We burn it in the boiler of the Lake Breeze. It was as good as any coal we used that season."

CAPT. R. M. BURLINGTON."

The following is an extract of a letter from Smith Bros., Jackson Michigan:

"We have disposed of the coal from your Rifle River mine and it has given first rate satisfaction. We are having inquiries for it every day. Our trade calls for about 500 tons. If you can supply us please answer."

A most favorable analysis of the coal for gas manufacture was given by Geo. F. Sherwood, superintendent and engineer of the Jackson Gas Works as follows: viz.

Charge of coal 4,800 pounds.
Gas made, 15,600 cubic feet.
Yield per pound, 3.25.
Burns freely, no clinkers, makes very hot fire."

* * * * * * * * *

Coal has been reported near Bellevue from eight to ten feet thick and 80 to 100 feet below the surface.[1] Bellevue itself is just outside the coal basin but a very few miles north coal is liable to occur in workable thickness. The above report is almost certainly exaggerated at least.

After what I have heretofore said I need hardly express my disbelief in coal near Norwood or anywhere far outside the coal basin as I have marked it out,[2] but it might occur at Howard City.[3]

TOPOGRAPHIC SURVEY.

We have mentioned that the field work for the Detroit quadrangle is practically complete.

A few elevations may be inserted here for reference.

The elevations in the following list are based upon a Coast and Geodetic Survey bench mark at Edward Hall's residence, Gibraltar. The elevation of this is accepted as 587.609 feet above mean sea level., the result of the Coast and Geodetic Survey adjustment of 1903.[4]

The leveling was done in 1901–02 under the direction of Mr. Robert Muldrow, topographer, by Mr. R. Wipfler, levelman.

All permanent bench marks dependent on this datum are marked with the letters "GIBRALTAR" in addition to the figures of elevation.

Gibraltar west along road to Flat Rock thence northwesterly to New Boston thence east to Trenton thence south to Gibralter.

	Feet.
Gibraltar, Edward Hall's residence; U. S. Coast Survey bench mark	587.609
Gibraltar, 2.5 miles west of; T. 4 S., R. 10 E., Sec. 36, near southwest corner of; 40 feet east of crossroads, northwest abutment of bridge	575.29
Gibraltar, 3.1 miles west of; T. 4 S., R. 10 E., Sec. 35, at southwest corner of; 90 feet south of crossroads, on large boulder	590.51
Flat Rock, in front of Dr. Turner's residence; on root of large maple tree	602.66
T. 4 S., R. 9 E., Sec. 27; at ¼ corner north side of bridge over Huron River, northeast corner of, on top of bolt in bed plate of	605.07
New Boston, .5 mile south of; T. 4. S. R. 9 E., Sec. 8, near center of northwest corner of bridge over Huron River, on top of bolt in bed plate of	625.16
New Boston, high bridge over Huron River; north east pier of, on top of rivet	620.54
T. 4 S., R. 9 E., Sec. 10, northwest corner of; 400 feet east of crossroads, north side of road, on root of tree	631.00

[1] Detroit News, 11: 25: 1904. Battle Creek Journal, Sept. 24, 1904, farm of Chas. G. Avery.
[2] Cheboygan News, 4: 5: 1904, slate 8 foot and coal? on Haak branch of M. C.
[3] Detroit News, Sept. 21, 1904.
[4] Which makes high water of 1838 of Lake Huron 584.69 that is .35 higher than the old value.

T. 4 S., R. 10 E., Sec. 11, northwest corner of; 400 feet east of crossroads, northwest corner of culvert, on top of bolt	596.63
T. 4 S., R. 11 E., Sec. 7, northeast corner of; at Sibley's station, at junction of River and Mud Roads, on top of stone post marked "U. S. H. L.-38 A"	588.24
Trenton corner of Washington and Pine streets, on top of hydrant	603.03
New Boston along road northwesterly via Ypsilanti to Ann Arbor, thence south to Saline thence east to New Boston.	
	Feet.
Ypsilanti, corner of North and River streets; on top of hydrant	713.90
Ypsilanti, corner of summit and Cross streets; in stand pipe, north side, bronze tablet marked "797 GIBRALTAR"	797.443

The following shows the condition of the work at present, and the cost. It will be noted that the U. S. Geological Survey has been very generous toward us.

Washington, D. C., Dec. 13, 1904.

Dr. Alfred C. Lane,
State Geologist, Michigan,
Lansing, Michigan.

Sir:

I have the honor to make herewith a preliminary report of the results of the co-operative topographic survey in the State of Michigan, for the year 1904-5:

Arrangements were made for the prosecution of this work under the terms of an agreement entered into between us on May 27, 1903, for the two years 1903 and 1904. On March 31, 1904, there remained a balance of government funds from the appropriation of the previous year of $453.75, and in addition $3,200 was allotted for the approaching year, making $3,653.75 of government funds available for the co-operative topographic surveys within the State. This, together with the $1,000 alloted by the State made a total of $4,653.75 available for the work of the season 1904-5.

From the expenditures made under the above, there has resulted a complete and accurate map of 252 square miles of the area of the State, which will be represented on the Detroit and Grosse Point sheets, scale 1:62500, and contour interval 20 feet, covering portions of the counties of Macomb, Oakland and Wayne. Incidental to the mapping of the Detroit sheet, the city of Detroit was surveyed on the large scale of 2,000 feet to the inch, with a contour interval of 20 feet, and will be published as a special map. There were run during the season 777 linear miles of road traverse; 302 miles of spirit levels, with 724 elevations, and 2 permanent bench marks.

After careful consideration it has been decided to publish the work done in co-operation, in southern Michigan at least, on the large scale, that of 1:62500, instead of the folio scale of 1:125000, on which the Ann Arbor sheet was published. Accordingly, four sheets, covering the Ann Arbor quadrangle, have been prepared on the larger scale and have been transmitted to the engraver; namely, Dexter, South Lyon, Saline and Ypsilanti; and the other three sheets than Detroit, covering the Detroit River two-mile sheet of last year, have been re-arranged for engraving on the larger scale under the names of Northville, Romulus and Wyandotte.

Very respectfully,

(Signed) H. C. RIZER,
Acting Director.

SURFACE GEOLOGY OF THE UPPER PENINSULA.

We have had considerable correspondence with Leo Geismar and others regarding maps of the surface geology and soils of the Upper Peninsula. The following is a sample letter:

Wells, Delta Co., Mich., Jan. 9, 1904.

ALFRED C. LANE, State Geologist, Lansing, Michigan:

My Dear Sir:

Your letter of Dec. 8th was duly received, and contents noted. In reply, would say that all we want in this connection is the general survey you outline in the latter part of your letter, giving the different types of soil and the different areas in which they are liable to occur, and pointing out their valuable qualities. We are compiling soil reports on each forty of land we own, made by our cruisers who go over the land from time to time, and this gives us all the information we need regarding one particular forty. We are getting up and sending out over the country pamphlets describing our lands and their value as agricultural lands; and we wish the survey made by your department to embody in same, as an official confirmation of what we say in regard to the region where our lands are located, viz, Delta, Marquette, Dickinson and Menominee counties. We have had brought to our notice a soil map of Wisconsin, made by the Geological Department of the state, which covers the matter as we would like to have it for this part of Michigan; and we therefore started the correspondence with Mr. Geismar and Mr. Fuller, to see if we could obtain something of the same kind. We would appreciate anything you can do for us in this regard; and we are sure you will recognize the good to this part of the State, outside of our previous interests, which would come of this work. We are earnestly endeavoring to combat the popular ideas which exist further south of us, that the Northern Peninsula is situated somewhere in the polar regions, and the land there is valuable only for minerals and timber.

We would be pleased to receive the atlas of Volume I part 1, of your reports, which you mention in your letter.

Yours truly,
(Signed) DANIEL WELLS,
Land Commissioner.

You accordingly employed Prof. Russell as a special expert in physiography and surface geology to cover that part of the Upper Peninsula which would be included in a nine sheet map with the Lower Peninsula, and his report is appended.

STRATIGRAPHY OF THE IRON BEARING ROCKS.

During August I was with a committee organized for the purpose of agreeing so far as possible as to the facts of "the succession and stratigraphy in the west half of the Lake Superior basin, including in the area, Michigan Minnesota and Western Ontario." The following is a letter regarding the same and the joint report:

Madison, Wis., March 10, 1904.

MY. DEAR DR. LANE:—

I had not written you of the contemplated international boundary work because I supposed that Dr. Hayes, chairman of the committee, would give you information in reference to our plans.

This committee consists of Dr. Bell and Dr. Adams on behalf of the Canadian survey, and Dr. Hayes and myself on behalf of the United States survey, with the understanding that interested geologists are to be invited to participate.

In reference to the Lake Superior work, it was decided that you as State Geologist of Michigan, or representative appointed by you, and Professor Coleman of the Bureau of Mines, should be invited to take part in our work. Or, if you desire, I have no doubt that Mr. Hayes will consent that both you and Mr. Seaman take part.

The plan for the coming summer is for the party to meet in the Marquette district as early in August as practicable, probably about the 2nd or 3rd, and spend all of that month, and as much of September as may be necessary to agree, if possible, upon the succession and stratigraphy in the west half of the Lake Superior basin, including in the area, Michigan, Minnesota and Western Ontario. I surely hope it will be practicable for the State survey of Michigan to have a representative on this joint field work.

Leith will also accompany us as having charge of the iron ore work for the United States survey.

Very truly yours,

(Signed) CHARLES R. VAN HISE,

REPORT OF THE SPECIAL COMMITTEE FOR THE LAKE SUPERIOR REGION.[1]

TO C. WILLARD HAYES, ROBERT BELL, FRANK D. ADAMS, AND CHARLES R. VAN HISE, GENERAL COMMITTEE ON THE RELATIONS OF THE CANADIAN AND THE UNITED STATES GEOLOGICAL SURVEYS.

INTRODUCTORY NOTE BY C. R. VAN HISE.

The report below of the special committee on the nomenclature and correlation of the geological formations of the United States and Canada is the first joint report of the geologists of the two countries. Before the death of Dr. G. M. Dawson, formerly director of the Canadian Geological Survey, I had correspondence with him in reference to joint field-work in the Lake Superior region. It was agreed between us that such field-work should be undertaken, but his untimely death occurred before anything was done.

After Dr. Dawson's death I continued correspondence upon the subject with Dr. Robert Bell, acting director of the Canadian Geological Survey. As a result of this correspondence, December 22, 1902, Dr. Bell wrote to Dr. C. D. Walcott, director of the United States Geological Survey, suggesting a conference in reference to the mutual interest of the two Surveys. This letter led to the appointment of a committee—consisting of C. W. Hayes and C. R. Van Hise, for the United States Geological Survey, and Robert Bell and Frank D. Adams, for the Canadian Geological Survey—to consider all questions as to the successions of formations, and as to nomenclature, which concerned the two surveys.

This committee, with C. W. Hayes as chairman, met for the first time at Washington, January 2, 1903. At this meeting several special committees were appointed to consider different districts along the international boundary. For the Lake Superior region the following committee was appointed: for the United States, C. R. Van Hise and C. K. Leith, of the United States Geological Survey, and A. C. Lane, state geologist of Michigan; and for Canada, Robert Bell and Frank D. Adams, of the Canadian Geological Survey, and W. G. Miller, provincial geologist of Ontario.

August 3, 1904, this special committee met in the Marquette district of Michigan, and during the six weeks following visited successively the Gogebic, Mesabi, Vermilion, Rainy Lake, Lake of the Woods, Animikie, and original Huronian districts. After finishing the field-work, a report in preliminary form was drawn up.

In December, 1904, another meeting of the special committee was held at Philadelphia, further to consider the report, all members of the committee being present except C. R. Van Hise. At this meeting the report of the sub-committee was completed as given below.

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[1] First printed in the Journal of Geology, pp. 89 to 104.

REPORT OF THE COMMITTEE.

Your special committee on the Lake Superior region, during the months of August and September, 1904, visited various districts in the Lake Superior country, their purpose being to ascertain, if possible, whether they could agree upon the succession and relations of the formations in the various districts, and could further agree upon a nomenclature appropriate to express the facts. The districts visited were the Marquette, the Penokee-Gogebic, the Mesabi, the Vermilion, the Rainy Lake, the Lake of the Woods, the Thunder Bay, and the original Huronian of the north shore of Lake Huron. Aside from the regular members of the special committee, for parts of the trip other geologists were with the party. Dr. C. W. Hayes, geologist in charge of geology, United States Geological Survey, and a member of the general committee, was with the party for the Marquette, Penokee-Gogebic, Mesabi, Vermilion, and Rainy Lake districts. Professor A. E. Seaman was with the party for the Marquette, Penokee-Gogebic, Rainy Lake, Lake of the Woods, and Thunder Bay districts. Mr. J. U. Sebenius was with the party for the Mesabi district, Mr. W. N. Merriam, for the Mesabi and Vermilion districts; Mr. W. N. Smith, for the Thunder Bay district; Mr. E. D. Ingall and Mr. T. D. Denis, for the Lake Huron district. The knowledge of these men was of great assistance to the committee.

In the following pages we shall give the successions and relations of formations which we believe to obtain for each of the districts visited, and give our opinion as to the major correlation of the rock series of the various districts, so far as this can be safely done, and the nomenclature which seems to best express the facts.

For each district, unless otherwise specified, the succession will be considered in descending order. In giving the successions for the various districts, we shall use, for convenience, the names suggested by geologists who have done the detailed work in the districts, without thereby expressing any opinion as to their appropriateness or their advisability.

In the Marquette district we found the upper series there exposed to be as follows: (1) Michigamme slate and schist, and (2) Ishpeming formation. Locally within the Michigamme slate, and apparently near its base, is an iron-bearing horizon. The Clarksburg volcanics, said to be a local phase of the Michigamme formation, were seen at Champion. The basal member of the Ishpeming formation is the Goodrich quartzite. This series, called the upper Marquette series by the United States Geological Survey, has at its base a pronounced unconformity, marked by extensive beds of conglomerate having materials of diverse character. The dominant fragments of the conglomerate at the localities visited are from the Negaunee formation to be mentioned below. The next series is the Middle Marquette series, consisting of (1) the Negaunee formation, (2) the Siamo slate, and (3) the Ajibik quartzite. In the publications of the United States Geological Survey this series was not separated from the series next mentioned, but the work of Professor Seaman has shown that there is a pronounced unconformity, marked by strong basal conglomerates at the bottom of the Ajibik. Below this unconformity is the Lower Marquette series, consisting of (1) the Wewe slate, (2) the Kona dolomite, and (3) the Mesnard quartzite. At the places where we saw the succession there is a belt of slate between the Kona dolomite and the Mesnard quartzite of such thickness that it might possibly be mapped as a formation if the exposures were

more numerous. The members of the United States Geological Survey think that this slate is probably general for the district, as it shows wherever the exposures are continuous from the dolomite to the quartzite. At the base of the lower Marquette series is an unconformity, marked by conglomerates bearing fragments of all the kinds of rocks seen in the underlying series. Two classes of fragments are especially abundant. These are (1) tuff, greenstone schist, and many kinds of greenstones which belong to the so-called green-schist series of the district, and (2) various kinds of granite and gneissoid granite. Adjacent to the state road south of the city of Marquette the actual contact was seen between the two series, the basal conglomerate resting upon the green schist. The great variety of materials in this conglomerate and the well rounded character of the fragments left no doubt in the minds of the members of the party that there is a great structural break at the base of the lower Marquette series.

The lowest group of the Marquette district is a very complex one, which has been designated as the Basement Complex. It consists of two classes of material—the greenstone-schist series, and the granites and gneissoid granites. The greenstone schist series is especially well known through the description of the late George H. Williams, found in *Bulletin* 62 of the United States Geological Survey. This series is designated on the maps of the *Marquette Monograph* as the Kitchi and Mona schists. Intrusive in the green schist series are great masses of granite and gneissoid granite. No evidence was seen by the party that any of the granites intrude the sedimentary series above the green-schist series, although Seaman thinks in one place a small mass of granite does intrude the Lower Marquette series. It is believed that the great masses of granite of the district antedate the three series here called Upper, Middle and Lower Marquette.

In the Penokee-Gogebic district the highest rocks seen are the Keweenawan traps and interbedded sandstones, the bedding of which dips at a high angle to the north. No actual contact between the Keweenawan and the next underlying series was seen, but north of Bessemer, below the Keweenawan, the next formation is the great Tyler slate formation of the Penokee series, while at Sunday Lake the Keweenawan rests directly on the iron-bearing formation which is stratigraphically below the slate. This relation led the party to infer the existence of an important unconformity between the two. The Penokee-Gogebic, or iron-bearing series, consists of (1) the Tyler slate, (2) the Ironwood formation, and (3) the Palms slate. This Palms slate was seen to rest directly upon granite south of the Newport and Palms mine. At the former locality there is no conglomerate at the base. At the latter locality there is a conglomerate at the base of the slate which, besides containing granite detritus, also contains many cherty fragments supposed to be derived from the next underlying sedimentary series.

East of the Presque Isle River the lower sedimentary succession of the Penokee-Gogebic district was visited, here consisting of (1) cherty limestone and (2) quartzite. The quartzite dips to the north at a moderate angle and rests upon green schist. The two formations were seen in direct contact for a hundred feet or more. The cleavage of the green schist abuts against the bedding of the quartzite at right angles. The quartzite near its base passes into a conglomerate, which, just above the contact becomes very coarse and contains very numerous well-rolled fragments of the immediately subjacent schist. The unconformity at the base of the quartzite could not be more pronounced.

The party nowhere saw the relations of the limestone-quartzite series just described and the Penokee-Gogebic series proper, but they have no reason to doubt the conclusion of the United States Geological Survey that the limestone-quartzite series is the inferior one.

The relations of the green schist, called Mareniscan by the United States geologists, and the granite, which together constitute the basement upon which the determined sedimentary series of the district rest, were not studied by the party. The United States geologists [1] hold that the relations are perfectly clear, and that the granite rocks are intrusive in the green schist.

In the Mesabi district the succession of the Mesabi series is as follows: (1) Virginia slate, (2) the Biwabik iron formation, and (3) the Pokegama quartzite. This series dips at a gentle angle to the south. At the base of this series at Biwabik is a conglomerate which rests upon a series of slates and graywacke, the latter in nearly vertical attitude. The unconformity between the two is most pronounced. The slate and graywacke where crossed has a considerable breadth. It flanks a green-schist series. The slate and graywacke formation adjacent to the green-schist is conglomeratic. Many of the fragments of the conglomerate are from the underlying green schists. At the locality visited it could not be asserted that the break between the slate-graywacke formation and the green-schist series is great, although nothing was seen which is contrary to this view. The granite constituting the Mesabi range is reported by the United States geologists as intruding both the green-schist and the slate-graywacke series, but not the Mesabi series. At the east end of the district a newer granite is reported as intruding both the Mesabi and the Keweenawan series, and in the central portion of the district small areas of granite porphyry are reported as antedating the slate-graywacke series.

In the Vermilion district the Upper series, where seen, consists of (1) Knife slates and (2) Ogishke conglomerate. The Ogishke conglomerate contains very numerous fragments of all the underlying formations noted—porphyries, green schists, iron formation, granite—and we have no doubt that there is a great structural break at the base of the Ogishke. The series below this unconformity, the Vermilion series, consists of (1) the Ely greenstone and (2) the Soudan formation. The Ely greenstone is the dominant formation. It is mainly composed of green schists and greenstones many of which show the ellipsoidal structure described by Clements. The other important formation of the Vermilion series is the Soudan iron formation. The structural relations of the Ely greenstone and the Soudan formation are most intricate. No opinion is here expressed as to their order. The Ely greenstone and the Soudan iron formation are cut by porphyries, and, according to the reports of the United States Geological Survey, are cut in a most complex way by the great northern granite, but the localities illustrating this were not visited. It is worthy of mention that the United States geologists report granite as intruding the Knife slates and Ogishke conglomerates in the central parts of the district, especially in the vicinity of Snowbank Lake, but this locality was not visited by the party.

In the Rainy Lake district the party observed the relations of the several formations along one line of section at the east end of Shoal Lake and at a number of other localities. The party is satisfied that along the line of section most closely studied the relations are clear and distinct. The Couchiching schists form the highest formation. These are a series of mica-

[1] My observations agree. See the rocks under the Ironwood water tank.

ceous schists graduating downward into green hornblendic and chloritic schists, here mapped by Lawson as Keewatin, which pass into a conglomerate known as the Shoal Lake conglomerate. This conglomerate lies upon an area of green schists and granites known as the Bad Vermilion granites. It holds numerous large well-rolled fragments of the underlying rocks, and forms the base of a sedimentary series. It is certain that in this line of section the Couchiching is stratigraphically higher than the chloritic schists and conglomerates mapped as Keewatin. On the south side of Rat Root Bay there is also a great conglomerate belt, the dominant fragments of which consist of green schist and greenstone, but which also contain much granite. The party did not visit the main belts colored by Lawson as Keewatin on the Rainy Lake map, constituting a large part of the northern and central parts of Rainy Lake. These however, had been visited by Van Hise in a previous year, and he regards these areas as largely similar to the green-schist areas intruded by granite at Bad Vermilion Lake, where the schists and granites are the source of the pebbles and bowlders of the conglomerate.

In the Lake of the Woods area one main section was made from Falcon Island to Rat Portage, with various traverses to the east and west of the line of section. The section was not altogether continuous, but a number of representatives of each formation mapped by Lawson were visited. We found Lawson's descriptions to be substantially correct. We were unable to find any belts of undoubted sedimentary slate of considerable magnitude. At one or two localities, subordinate belts of slate which appeared to be ordinary sediment, and one belt of black slate which is certainly sediment, are found. In short, the materials which we could recognize as water-deposited sediments are small in volume. Many of the slaty phases of rocks seemed to be no more than the metamorphosed ellipsoidal greenstones and tuffs, but some of them may be altered felsite. However, we do not assert that larger areas may not be sedimentary in the sense of being deposited under water. Aside from the belts mapped as slate, there are great areas of what Lawson calls agglomerate. These belts, mapped as agglomerates, seem to us to be largely tuff deposits, but also include extensive areas of ellipsoidal greenstones. At a number of places associated and interstratified with the slaty phases are narrow bands of ferruginous and siliceous dolomite. For the most part the bands are less than a foot in thickness, and no band was seen as wide as three feet, but the aggregate thickness of a number of bands at one locality would amount to several feet.

We could discover no structural breaks between the above formations of the Lake of the Woods. The various classes of materials—slates, agglomerate, and ellipsoidal greenstones—all seem to belong together. In short these rocks in the Lake of the Woods seem to us to constitute one series which is very largely igneous or volcanic in origin, but does, as above mentioned, contain some sediments. This series in the Lake of the Woods area is the one for which the term "Keewatin" was first proposed for the greenstone series, Lawson giving as one reason for proposing this name the statement that there is no evidence that these rocks are equivalent with the rocks of Lake Huron described by Logan and Murray as Huronian.

The ellipsoidal greenstone-agglomerate-slate series is cut in a most intricate way by granite and granitoid gneiss, which constitute much of Falcon Island at the southern part of the Lake of the Woods and a great area

north of the Lake of the Woods. These relations between the granite and Keewatin were seen on the northwest part of Falcon Island and on a small island adjacent. They were also seen north of Rat Portage. At the latter place the rocks adjacent to the granite are banded hornblende and micaceous schists, very similar to the banded rocks of Light House Point, at Marquette. At Hebe Falls the granite and Keewatin series are seen to be in actual contact, the Keewatin being apparently intruded by the granites, although the relations have often been interpreted as conformable gradations. Going north along the Winnipeg River, the relations between the two series become perfectly clear. Great blocks of the Keewatin are included in the granite, the masses varying from those of small size to others of enormous bulk. Also the two have intricate relations, which have perhaps been best described as *lit par lit* injection. In short, the relations are those so well described by Lawson for this area.

In the Thunder Bay district we visited especially the areas about Loon Lake and Port Arthur. In the Loon Lake area the succession is as follows: The top series is the Keweenawan, here consisting of sandstone above and conglomerate below, with interbedded basic igneous flows or sills. Below the Keweenawan is the Animikie. The contact between the Keweenawan and the Animikie was seen at two places. At one of these there is an appearance of conformity, but at the other the eroded edges of the Animikie iron-bearing formation are traversed by the Keweenawan beds. At one contact the base of the Keweenawan rests on the Animikie slate, interstratified with the iron formation, and at the other on one of the members of the iron-bearing formation. At both localities the conglomerate at the base of the Keweenawan bears detritus from the underlying series, including both the slate and the iron-bearing formations of the Animikie. The Animikie succession which we saw near Loon Lake includes two phases of the iron-bearing formation with an interstratified belt of slate. The Animikie here has in general rather flat dips, although locally they become somewhat steeper.

Near Port Arthur the higher slate member of the Animikie was visited by a portion of the party, and on previous occasions had been visited by the other members. This is the formation which is agreed by all to rest upon the Animikie iron formation. It is notable as containing the intrusive sills called by Lawson the Logan sills.

At one place near Loon Lake a test pit has been sunk to the bottom of the Animikie, and here at the base of the formation is a conglomerate bearing fragments of the next underlying series—a graywacke slate. This graywacke slate covers a large area, shows cleavage at a high angle, and is evidently an important formation in the district.

The party has no doubt that there is considerable unconformity between the Keweenawan and the Animikie and a very important unconformity between the Animikie and the graywacke slates.

A portion of the party went north from Port Arthur to see the greenschist and granite series. This was found, but seen only in small volume at the particular area visited. At other times several members of the party have visited larger areas of this green-schist and granite complex north and northwest of Port Arthur in Gorham, Conmee, and other townships, and in the green schists they found an iron-bearing formation analogous in character to the Soudan formation of the Vermilion district. The granites are intrusive in the greenstones.

At no place were the relations between the graywacke slate series below the Animikie and the green-schist granite complex observed.

In the original Huronian area—i. e., the area described by Logan and Murray as extending from near Sault Ste. Marie along the north shore of Lake Huron to Thessalon and northward—we examined a number of crucial localities. At the first of these about five miles from Sault Ste. Marie, near Root River, we studied the relations of the conglomerate, mapped as lower slate conglomerate by Logan, with the granite. The conglomerate is in a vertical position. We found the upper horizon of the conglomerate near the road to be of moderate coarseness, and to contain many fragments of green schist, greenstone and granite. The granite fragments increase in prominence and size toward the north, and at the north end of the exposure we have a great granite conglomerate. After an interval of a few paces we found to the north a red granite similar to many of the fragments of the conglomerate. The party has no doubt that the conglomerate rests unconformably upon the granite. This conglomerate, while mapped by Logan as lower slate conglomerate appears to be above a limestone next to be mentioned, and has been connected by Van Hise and Leith with rocks like the red quartzite belonging above the limestone, and they believe it to be the upper slate conglomerate rather than the lower slate conglomerate, although the overlapping recent lake deposits prevent the connection by actual areal tracing. A short distance east of the point where the conglomerate is next to the granite and north of the great mass of the conglomerate is a belt of limestone which continues east for perhaps half a mile. North of this limestone is conglomerate, and still to the north, granite. This northern conglomerate is very similar to the conglomerate south of the limestone, and two interpretations are possible as to its position: it may be regarded as the lower slate conglomerate under the limestone, or it may be regarded as an equivalent to the conglomerate south of the limestone, being repeated by an anticline or possibly a fault. The limestone has a steep dip to the north, and, accepting either alternative, it must be regarded as overturned.

We next visited the abandoned limestone quarry north of Garden River station. Here we found the conglomerate, marked by Logan as the upper slate conglomerate, within a few paces of the limestone. This conglomerate is in all respects similar to the average of the conglomerates before mentioned, except that it contains very numerous limestone fragments. The party has no doubt that the limestone formation was laid down, and that a considerable erosion interval occurred before the deposition of the conglomerate upon the limestone. The slate conglomerate belt north of the limestone was examined, and while it was not found in contact with the limestone, it was seen to increase in coarseness as the limestone is approached, and across the little ravine which separates the conglomerate from the limestone it was found to contain numerous limestone fragments. We therefore conclude that the rock on each side of the limestone is the upper slate conglomerate, the structure probably being anticlinal, possibly with faulting. This conclusion suggests that the same relation obtains at the Root River locality above described.

On the limestone point on the east side of Echo Lake we found the following ascending succession, with monoclinal dip to the southeast: (1) white or gray quartzite, grading through graywacke into (2) a thin belt of conglomerate not exceeding twenty feet in thickness and containing num-

erous granite fragments. Above the conglomerate is (3) limestone in considerable thickness, and over this (4) the upper slate conglomerate. This last is a thick formation. The upper conglomerate is very coarse near the limestone, and becomes finer in passing away from the limestone along the lake shore. Like the conglomerate near Garden River, it bears very numerous limestone fragments, the evidence of which is beautifully seen at the lake shore, where the water has dissolved many of them completely and others in part. The ledge thus presents a deeply pitted surface, many of the pits being several inches in depth.

On the west side of Echo Lake we ascended the prominent bluff next north of the west limestone point, and here found the formation nearly horizontal, but dipping slightly into the hill. The quartzite in this position composes the greater part of the bluff. A short distance from the top we found the quartzite grading upward into a graywacke-like rock, and this into a conglomerate which contains granite and green-schist fragments; indeed, it is typical slate conglomerate. This conglomerate is only a few feet in thickness, and above it appears a siliceous limestone, and above this, normal limestone like that of Garden River and the east side of Echo Lake. The total thickness of the limestone here seen was probably not more than fifty feet, and of the conglomerate below, not more than thirty feet. The lower five hundred feet or more of the bluff is the white quartzite.

The other bluffs on the west side of the lake were not visited by the party, but Leith, Seaman and Van Hise have examined each of these bluffs, and found the succession above given to obtain upon each prominent bluff, with the exception that on the next bluff to the north the limestone is wanting, so far as observed. The limestone is also in greater force on some of the other bluffs, but is always subordinate in thickness to the quartzite. It thus appears that the great formation on the west side of Echo Lake is the quartzite; that the limestone above appears, not as a single belt, but as a number of synclinal patches often capping the hills; and that the conglomerate showing both north and south of the limestone is a very thin formation between the quartzite and the limestone, and is, therefore, the lower slate conglomerate.

Our observations from Root River to Echo Lake convince us that there is a considerable structural break in the Huronian. The upper series includes the following formations of Logan, viz.: white quartzite, chert, and limestone, yellow chert and limestone, white quartzite, red jasper conglomerate, red quartzite, and upper slate conglomerate. The lower series includes the lower limestone of Logan and the lower slate conglomerate, white quartzite, and gray quartzite. North of Thessalon the two series are represented by Logan and Murray as being separated by a fault. Here the distribution may be explained by the unconformity mentioned, but it is also entirely possible that the relations are due to faulting or to both unconformity and faulting.

Four miles east of Thessalon on several islands off the coast is a great conglomerate, mapped by Logan and Murray as gray quartzite. This conglomerate was found to rest unconformably upon the granite, the actual contact being observed upon one island opposite the northwest quarter of Sec. 12 of the Township of Thessalon. The fragments in the conglomerate are well rounded and are largely granite, but there are also numerous pebbles and bowlders of greenstone and green schist. On several islands adjacent to the conglomerate the massive granite includes many fragments

of greenstone and green schist, showing the granite to be intrusive into a greenstone formation. Thus in the complex against which the conglomerate rests we have a source both for the granite and greenstone pebbles and bowlders. To the northwest the conglomerate grades up by interstratification into a quartzite. About a quarter of a mile west of the conglomerate, near the north end of a point, the quartzite is found to become a fine conglomerate, and to rest against greenstone which is cut by a large granite dike. The greenstone shows ellipsoidal parting. The granite dike strikes toward the conglomerate and the quartzite, but it dies out into a depression showing no rock, which continues to the quartzite some fifty or sixty feet distant. The quartzite and conglomerate strike directly across this depression, showing continuous exposures, and are not cut by granite. The relations here are believed by certain members of the party to show clearly that the quartzite and conglomerate rest unconformably upon the greenstone, but other members felt that this conclusion is not certain. The conglomerate and gray quartzite are cut by greenstone dikes. Similar rocks also cut the Thessalon series referred to below.

The rocks called green chloritic schist by Logan (3c) will here be called the Thessalon series. This series consists of ellipsoidal greenstones, amygdaloids, agglomerates, and massive greenstones. No undoubted sediments were observed in the series. The relations of the Thessalon series to the granite were observed southeast of Little Rapids, and it was found that the granite cuts the greenstone series in an intricate fashion. The belt of gray quartzite, mapped as extending inland for a number of miles between the Thessalon series and the granite, was found to be absent at this locality. Two or three miles east of Thessalon, felsite and granite in considerable masses were found to intrude the Thessalon series. At one place several felsite or granite dikes were observed to cut both the agglomerates and ellipsoidal greenstones. From the relations observed, the party had no doubt that the conglomerate islands east of Thessalon belong unconformably upon the granite, and they think it probable (Van Hise would say highly probable) that the quartzite and conglomerate rest unconformably upon the Thessalon series, mapped as green chloritic slate by Logan and Murray. It is regarded as probable that the white quartzite below the lower slate conglomerate northwest of the Thessalon series which is adjacent, and is shown by its dip to rest upon the Thessalon series, is separated from that series by an unconformity, but no direct evidence of such relation was observed.

The Thessalon series should be excluded from the Huronian if, as believed, the unconformity just mentioned exists. If this series be excluded, the Huronian of Lake Huron consists of two series, an Upper Huronian and a Lower Huronian. The Upper Huronian extends from the top of the series as given by Logan and Murray, downward to and including the upper slate conglomerate; and the Lower Huronian extends from the main limestone formation to the gray quartzite, including its basal conglomerates. In the area mapped by Logan on the north shore of Lake Huron the Laurentian consists of granite and gneissoid granite, with subordinate inclusions of greenstone.

We do not feel that our examination of the Lake Superior region was sufficiently detailed to warrant an attempt at correlation of the individual formations of the various districts. There are, however, certain general points which seem to be reasonably clear, and about which there is no difference of opinion between us. These are as follows:

There is an important structural break at the base of the Keweenawan. The term "Keweenawan" should include substantially all of the areas which have been thus mapped, or mapped as Nipigon, by the Canadian and United States Surveys, and the State Surveys of Michigan, Minnesota and Wisconsin.

Below the Keweenawan is the Huronian system, which in our opinion should include the following series: In the Marquette district, the Huronian should include the Upper and Lower Marquette series, as defined in the monographs of the United States Geological Survey, or the Upper, Middle, and Lower Marquette series, as given in the previous paragraphs. In the Penokee-Gogebic district, the Huronian should include the series which have been called the Penokee-Gogebic series proper, and the limestone and quartzite which have local development, and which we visited east of the Presque Isle River. In the Mesabi district, the Huronian should include the Mesabi series proper, and the slate-graywacke-conglomerate series, unconformably below the Mesabi series. In the Vermilion district the Huronian should include the Knife slates and the Ogishke conglomerates. In the Rainy Lake district, the Huronian should include that part of the Couchiching of the south part of Rainy Lake which is limited below by basal conglomerate as shown at Shoal Lake. In the Thunder Bay district, the Huronian should include the Animikie and the graywacke series in the Loon Lake area. In the original Huronian area, the Huronian should include the area mapped by Logan and Murray as Huronian, except that the Thessalon greenstones should probably be excluded.

Unconformably below the Huronian is the Keewatin. The Keewatin includes the rocks so defined for the Lake of the Woods area and their equivalents. We believe the Kitchi and Mona schists of the Marquette district, the green-schist (Mareniscan) of the Penokee-Gogebic district, the greenstone series of the Mesabi district, the Ely greenstones and Soudan formation of the Vermilion district, the part of the area mapped as Keewatin by Lawson in the Rainy Lake district not belonging structurally with the Couchiching, and probably the Thessalon greenstone series on the north shore of Lake Huron, to be equivalent to the Keewatin of the Lake of the Woods, and, so far as this is true, they should be called Keewatin.

For the granites and gneissoid granites which antedate, or protrude through, the Keewatin, and which are pre-Huronian, the term "Laurentian" is adopted. In certain cases this term may also be employed, preferably with an explanatory phrase, for associated granites of large extent which cut the Huronian, or whose relations to the Huronian cannot be determined.

The following succession and nomenclature are recognized and adopted:

CAMBRIAN—Upper sandstones, etc., of Lake Superior

Unconformity

PRE-CAMBRIAN

Keweenawan (Nipigon)[1]

Unconformity

Huronian
- Upper (Animikie)
- *Unconformity*
- Middle
- *Unconformity*
- Lower

Unconformity

Keewatin

Eruptive contact

Laurentian

Alphabetically signed by the committee as follows:

FRANK D. ADAMS,
ROBERT BELL,
A. C. LANE,
C. K. LEITH,
W. G. MILLER,
CHARLES R. VAN HISE,
Special Committee for the Lake Superior Region.

PERSONAL COMMENTS,—KEWEENAWAN.

It remains to add certain comments on the same.

The committee did not examine the relations of the Keweenawan to the Lake Superior sandstone (Cambrian), having occasion only to note at Loon Lake its unconformity upon the Huronian, and the intrusion of sills of basic rock, presumably Keweenawan, into the Animikie (neo-Huronian).

I am inclined to believe personally with Prof. Seaman that the Keweenawan is Cambrian, and as my predecessors have classed it as Cambrian[2] I do not see that it is wise to change. However, I realize that the evidence

[1] Mr. Lane dissents as to the position of the Keweenawan as follows:
"The use of pre-Cambrian above does not imply unanimity in the committee with regard to the pre-Cambrian correlation of the Keweenawan—a topic the committee as such did not investigate."

[2] Rominger (Hubbard) Volume V., part 1, p. 90. Wadsworth. Report 1891-1892, p. 85.

upon which I depend is not coercive, and that it is possible that the Keweenawan may antedate in part or in whole the Acadian fauna. And as the U. S. Geological Survey have for the past twenty years consistently classed the Keweenawan as pre-Cambrian, I should not expect them to change their classification, unless morally certain they were right in so doing.

Thus for the present we must agree to disagree, but use the unambiguous term Keweenawan so far as possible.

Let us look a moment at the evidence:

1. The Keweenawan is *very thick*, but this thickness is composed of rocks which may accumulate with extreme rapidity, sandstones, conglomerates, and sheets of trap, single flows of which are hundreds of feet thick. So that geologically it may represent no greater time than the Iceland deposits.

2. Its lithological character is such that fossils would hardly be expected.

3. Intense volcanic activity characterize its middle and lower part. Intrusions occur in the lower part. Conglomerates and sandstones are often derived from material of the formation itself. We even find pebbles of lower Keweenawan agates and intrusives in the upper Keweenawan.

4. We are therefore prepared to find, as we do, that the lower part has steeper dips, more faults with greater throws and was evidently much disturbed, before the upper Keweenawan was laid down.

5. The lower Keweenawan, which is overlain very unconformably by the [illegible] Lake Superior Potsdam sandstone, also stands in the same relation to the upper Keweenawan.

6. There is a fairly steady upper Nimakin limit, lithological character, geographical position and degree of metamorphism from the base of the Keweenawan to its upper members of the Lake Superior sandstone.

7. The [illegible] gradually dying out, and one [illegible] I do not know of any [illegible] upper Keweenawan before the lay[illegible] Lake Sandstone which may be conceived as a [illegible] practically [illegible] that may be derived from this Ke[illegible]

[illegible] Keweenawan. Range [illegible] the unconformable [illegible] the Kewee[illegible] caught in the Lime[illegible] Lake Supe[illegible] I have not been [illegible] time interval [illegible] Lake Superior [illegible]

[illegible] upper Keweena[illegible] pretty closely in [illegible] black slates [illegible] which the Ke[illegible] Animikie [illegible]

[illegible] assemble

[illegible] speak of

MARQUETTE RANGE.

In regard to the Marquette range the stratigraphic succession is the same as has been held for some time by Prof. Seaman and myself. In the revised map of the region which the U. S. Geologists are preparing there will be a larger recognition of faults than heretofore, and were I drawing the map, there would probably be more yet. I also spent a week with Prof. Seaman in the region about Goose Lake in the early spring. The mapping there will need to be extensively revised. The Ajibik formation with the conglomerate at its base runs diagonally across the bed of the Ajibik hills, the main part of which is apparently Mesnard, eo-Huronian. The south side of the hills is a fault scarp and according to Mr. A. Formis a 1,400 foot drill hole just south passes through quartzite (the Goodrich, neo-Huronian) and then ore all the way. A fault probably also runs northeast and just east of the Volunteer mine. The three over-lapping quartzites and conglomerates make a complex which no one can be blamed for mistaking at times.

Along the edge of the bluffs east of Teal Lake in Sec. 31, T. 47 N., R. 26 W. the Mesnard series is terminated by the Ajibic which runs nearly east and west, while the latter is more nearly N. 70 degrees, and is I think badly faulted, blocks of slate and of Mesnard quartzite, being let in irregularly. I believe there are small faults also where the Carp river emerges on the sand plain and where the road on Sec. 31 passes through the wall made by the upturned quartzites. Prof. Seaman's class is engaged in working the former set out. According to Seaman the column of the eo-Huronian or Mesnard series is, beginning at the top:

Unconformity
Kona dolomite, massive
Thin shabby dolomite
Cherty quartzite
Slate
Quartzite
Slate belt
Main Mesnard quartzite
Quartz slate or flags
Conglomerate
Main unconformity.

The county has been subject to a stress such that the east and west shearing is made by a movement of the north side to the east generally, while along certain northwesterly joints the north side is thrown west. Such a fault I think comes down the Carp in Sec. 33, T. 47 N. R. 26 W.

There is a great fault running from Sec. 6, T. 48, R. 25, to Sec. 11, T. 47, R. 26 and the big mass of intrusives in Sec. 10.

The maps of the Marquette Monograph, while extremely useful, were drawn particularly with the iron question in view, and might be improved in many ways, and will be by the U. S. Geological Survey in the forthcoming Monograph, especially so far as they concern the iron bearing rocks. But there are certain classes of changes which I do not expect that they will make, though they should be made sometime. For instance the basic igneous rocks they have distinguished almost solely in connec-

tion with the Negaunee formation where they assume an especial economic importance. But they are of course quite abundant in the other formations.[1]

The question whether they are intrusive or effusive has not been touched. To a considerable extent they are intrusive and perhaps coeval with the effusives of the Clarksburg formation of the neo-Huronian and the green tuffs of the Palms formation, way over in the Gogebic range. Others are older effusives. Others are probably even Keweenawan in age. Section 26, T. 47, R. 27 is also a section where faults probably occur. The general dip is to the north and the succession from above.:

Siamo slate
Amphibolite (intrusive?)
Greenstone schists
Quartzite
Greenstone schist much disturbed and near a fault or intrusion.

These maps have paid little attention to the Marquette brownstone and other outliers of the Lake Superior sandstone which have no especial interest to the iron miner. They are of interest to the quarryman and may be so to the gold miner.

I think it quite desirable to prepare in co-operation with the U. S. Geological Survey at least in the topographic base, a map, more thorough in all respects, of the Marquette quadrangle, which would be of use to the Marquette Normal school and also the College of Mines.

THE LAURENTIAN PROBLEM.

South of the Cascade Range and thence west is a great area of rocks, largely granite, mapped by Brooks and Pumpelly in Volume I of our reports (Plate 1) as Laurentian, which the U. S. Geological Survey include as Archean and mainly granite. That a large part of the area is composed of intrusive plutonic rock there can be no question, but its relation to other formations has been a subject of controversy. Some granites were discovered by Brooks and Rominger to be intrusive in undoubted Huronian. The contact with the greenstone schist (Kitchi, Mona, Palmer gneiss) series is apparently always intrusive, and it is possible that the Palmer gneiss south of the Volunteer mine is but a granitized arkose quartzite possibly equivalent to the Mesnard. Thus Rominger[1] saying that the lower granitic and gneissoid portion of the rock group in the Marquette region exhibits the character of an eruptive and not of an altered sedimentary rock, expunged the term Laurentian from his column.

Seaman has found on Sec. 26, T. 48, R. 27, indications that the granite does intrude the quartzite.

According to many of the Canadian geologists, and they have had remarkable opportunities to see the facts, these granites are however the softened base of the geological column, more or less squeezed up into the overlying strata, and Rominger agrees with them as to the facts.[2]

Now no one would deny that they come from somewhere below the strata

[1] For instance in the Kitchi schist at Lighthouse Point Marquette, also on Ropes mine road 1750 N. 510 W. Sec. 33, T. 48, R. 27.
[1] Volume V, Part 1, page 2.
[2] Volume V, Part 1, page 3.

into which they are intruded, but so do the intrusives which we find everywhere in the geological column, and that these granite gneisses should be entitled to a permanent place in the stratigraphic column of rocks below some other, to my notion it should be necessary to show that they were indeed the next underlying formation and not from some layers of the crust much farther down, and in part in some places to some extent at least the crystalline texture should almost surely antedate the intrusion.

There is, so far as I have observed, no trace of superficial structures of any kind in these rocks. Apparent fragments (not counting those obviously faulted in) are probably more or less absorbed parts of the strata into which they were intruded, possibly sometimes secretions or clots of the earlier formed crystals aggregated in the crystallizing magma, though some might consider them non-liquified remnants of old strata. Crystallization under pressure in the presence of water and heat, this appears to me to be the dominant factor. Throughout our trip I had this question in mind and desired particularly to see what indications there might be, from the variation of grain, of a difference in conditions between the intruding and intruded rock, for if the Laurentian granites are but a softened and intruded basement, we should imagine that there would be no great difference in conditions between them and the rock into which they were intruded. Now I have shown[1] that, other things being equal, the grain at the center of a great intrusive mass if it is fairly uniform is coarser the nearer the conditions of the country rock and those of the mineral whose grain is studied are, (g inversely proportional to the square root of u). The grain at or near the margin may be greater or less than that of the uniform grain at the center, the size it will attain depending in a rather complex way both on the distance from the margin and also on the initial conditions (temperature) of formation of the country rock and the mother rock relative to the intrusion of the magma: a coarser grain for a given mineral immediately at the margin than farther in indicating that the country rock is nearer the range of formation of the mineral than the intruded rock originally was.

The degree of extra coarseness at or near the margin may be used to find in a numerical way the relative nearness of country rock and intruded rock to the conditions of formation of the mineral studied.

Now from such studies as I was able to make, I inferred especially from the grain of the feldspar that: (1) The so-called Laurentian granites were reasonably fine grained far from the margin, whether intrusive in the Upper Laurentian (Keewatin) or Huronian, and apparently were more separated from the rocks they intruded in conditions of consolidation than many pegmatite granites, and as much as many granites. They are for instance finer grained than a 15-foot tourmaliniferous dike with 30 mm. feldspars, that we found cutting a trap dike on the Loon Lake range. Granite dikes are often coarser than the great batholites. (2) On the other hand the country rock was distinctly nearer the conditions of consolidation of the granite (at least the quartz and feldspar thereof) than it has generally proved to be to those of the consolidation of the augite and feldspar of traps and diabases, such as the Logan sills, so that the granites were probably deep seated rocks, and *the rocks into which they were intruded may have been nearly softened, but the granite magma itself appears to have been materially deeper seated and more fluid.* (3) Not infrequently, in fact I think gener-

[1] Report for 1903, pp. 205 to 234.

ally, there was a porphyritic appearance of the granites near the margin due to more conspicuous feldspar crystals near the margin, which is an indication that the original condition of the country rock was nearer that of feldspar formation than the original condition of the granite magma, (when it came to rest and perhaps after enclosures had materially cooled the margin more than the center) the latter being hotter, the former cooler.

I do not pretend to be the first by any means to have noticed this tendency to a porphyritic appearance of the Laurentian granite gneisses, which for instance in this very Lake Superior region has been remarked by Rominger,[1] Winchell and Grant and Lawson[2] and Rosenbusch even in his 1887 edition (p. 41) alludes to the porphyritic marginal facies. But I do not think they have drawn the inferences from it that I do, nor have they called attention to the fact that the porphyritic feldspar for instance often gradually develops in size as one approaches the margin and is therefore not an early intratelluric product but a true margin crystal (oriocrystal) coarse because there was an extra long time that the interchange of conditions between the hot mother rock and the country kept the margin within the range of their formation.

Just for illustration suppose the gneiss consolidated at a depth of 5 to 10 miles and a pressure of 2,160 to 4,050 kilos per square centimeter, and the rocks into which it was ejected were previously at a temperature of 200 degrees to 420 degrees C.[3]

Suppose also that the orthoclase was formed at 500°C a temperature at which it has been made in the presence of mineralizers. Then I think it probable that the granite magma has an original temperature of not less than, and probably not very far from, 500°+(500–200° or 420°) 800° to 580° corresponding to an original greater depth of four miles or more.

The following detailed observations seem to me to substantiate what I have said. The rock at International falls (Couchiching or Koochiching) and Fort Frances, where Rainy river plunges over some 20 feet, has been described by A. N. Winchell[4], Winchell and Grant[5] and Lawson.[6]

"The rock is a medium gray biotite syenite; the component minerals are white feldspar and biotite with a little hornblende and epidote." "A section of this rock shows it to be a granular aggregate of orthoclase, plagioclase, and biotite with a little necessary hornblende and quartz, in which are embedded porphyritic crystals of orthoclase. Other accessory constitutents are sphene, apatite and magnetite. The..... plagioclase .....is probably oligoclase."

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[1] Geol. Survey of Mich., Volume 5, Part 1, p. 4, and 6.

[2] Lake of the Woods report, 29 cc. 30, 63. Rainy Lake report, 126, 127, 128, 130.
See also: W. O. Crosby, American Geologist, Vol. XXV, May 1900,p. 301; L. V. Pirrson, Am. Jour. Sci., 157, pp. 271 to 280. It will be noticed that they both, Crosby and Pierson are trying to explain a porphyritic texture at the center, which also occurs in granites, for instance that of Carvel hill which I have described with Crosby, while in these Laurentian cases, the porphyritic texture is marginal, and the porphyritic feldspare is coarser than any farther in. In this it differs from the fine grained porphyritic texture at the margins of diabase dikes.
As may be seen I am inclined to attribute the variations in porphyritic character to differences in the relations of the initial condition of the intruding rock, the conditions of consolidation and the conditions of the intruded country rock, the latter being nearer the conditions of crystallization when the country rock is coarser.
I shall not enter into controversy regarding the theories. To determine the relative value of various explanations we must have more numerous careful examinations of series of rock specimens at known distances from the margin. My explanation is certainly capable of being a true cause. How often it is the efficient cause remains to be seen.

[3] It is quite possible that early in geological time the rocks would be hotter than these temperatures which correspond to an increase in temperature of only 3° C. in 100 meters or 1° F. for 60 feet.

[4] Geol. and Nat. Hist. Survey of Minnesota, Volume IV, p. 1002; American Geologist, XX, 293 to 299.

[5] Preliminary report on the Rainy Lake gold region. Minn. Geol. and Nat. Hist. Survey, 23rd annual report, pt. 3, 55, 221.

[6] Rainy Lake report, p. 126 F.

"It contains many darker masses sometimes a foot or more in diameter," which (as Winchell and Grant suggest as one possibility) are according to Dr. Adams most probably inclusions of the country rock the contact with which, as we shall see, was not far off, and these may have affected the chemical composition of the whole rock giving it its relatively basic nature. "Below the falls the rock becomes porphyritic with crystals of feldspar which are often an inch in length. The crystals stand out all over the weathered surfaces of the rock. Two islands about three-fourths of a mile below the falls contain excellent exposures of this rock; the upper of these islands is composed of syenite alone, while the lower also shows a fine micaceous schist which in places is seen in sharp contact with the syenite, and in other places there is apparently a transition from the syenite to the mica schist within the distance of a few feet." "Two exposures of the syenite occur on the Minnesota side," "the second is near the N. ½ of the N. W. ¼ Sec. 25, T. 71—24. At the latter outcrop the rock is porphyritic with feldspar crystals."

In Volume V of the Minnesota Reports it is classed as a hornblende biotite granite, but while there is some micropegmatitic primary quartz, I do not think it would ordinarily be classed as a granite. Orthoclase, biotite, and andesine oligoclase are said to be common, microcline and quartz, perhaps in part secondary, hornblende in part after augite epidote, apatite (secondary?), and kaolin occur. Zoisite is reported (but I suspect may be epidote) calcite, muscovite, and pyrite are doubtful or rare. Titanite and tourmaline are accessories.

So far the observations are of others which my own confirm.

At the falls the river turns and flows across the formation, i. e. across the prominent jointing and at right angles to the general trend of the formation and gneissoid banding of the syenite.

At the foot of the falls it turns again at right angles and flows with the formation S. 71° W., with shelving ledges of the syenite plunging into the water almost continuously on the south side and no exposures on the north side until the islands referred to. At Fort Frances where there is a large amount of fresh material thrown out from the abandoned lock, the syenite is not noticeably porphyritic. The feldspar dimensions are not over 10 mm, usually 3 to 4 mm the mica about the same and across the falls on the American side the grain is about the same, though there are a few larger laths (15 x 2 mm to 10 x 1 mm being measured). At the foot of the falls where the turn comes however the porphyritic texture is plainer, the larger feldspars (but apparently not a separate generation) being 17 x 4 mm. Following down river 176 feet we find them about the same 17 x 5 mm, 264 feet farther a little coarser 21 x 6 mm, 77 feet farther a dike, 209 feet farther another 6 feet wide striking north of the east and dipping south, 60 feet farther another only 3 feet wide, 165 feet farther another 4 feet wide the dip still south, the porphyritic feldspar of about the same size 17 x 4 mm, 60 feet farther on a dike striking S. E. and dipping at a pretty flat angle to the south, 165 feet farther a dike running along shore and dipping pretty steeply to the south, 100 feet farther on it remains about the same text and the feldspar 21 mm or so in length. The grain continues about the same down opposite to the islands above mentioned, where the contact was said to be. The nearly uniform size of the feldspar crystals on the river going along the course S 71° W. suggests that the river here is running parallel to the contact line, parallel to which is the pronounced jointing already men-

tioned. And this is also indicated by the tendency of the dikes noted to dip off the south. But if so, thought I, why should not the rock be equally porphyritic following the line of strike across the falls of the Canadian side? My first observations were made August 10th, and on August 20th I had a chance to revisit the falls for a few hours and found the explanation in a well marked fault which runs through the Canadian lock, and the syenite which is somewhat porphyritic south of it is not at all so to the north. This fault plane dips 60° to south and strikes more nearly west than the general strike of the irregular intrusive contact probably. The bit of Couchiching at the mouth of the river which we examined appeared to be a bit of the contact rock of this granite in which dikes, probably originally ordinary augite trap dikes were turned to hornblende schist and the original sandstones and shales to hornfels and mica schist.

About three miles east (Sec. 28, T. 71 N., R. 23 E.) are a couple of small islands which we visited where the same general contact is exposed, but the gradual development of the porphyritic appearance is even plainer, as the contact is approached. The northwest corner of the farthest island is farther from the contact. The mica is there coarsest 2 mm, the feldspar 2 to 4 mm, the quartz 1 to 2 mm. There are numerous mica enclosures or secretions. At the south end of this island it is distinctly porphyritic, the larger feldspars, which have irregular contact with, and enclosures of, the others minerals being 15 x 7 mm in size. The mica is about 1 mm, the quartz 2 to 4 mm. An aplitic dike is coarsest at margin. To the immediate contact the porphyritic appearance persists, and there are fragments of the schists in the granite and they are intruded and altered by the gneiss. Other instances have been described by Lawson, and I know no other writer who more clearly recognizes the grain as a function of the slowness of cooling or more exactly described the phenomena. All that I add is a reduction of the matter to a numerical basis, and the inference that while the intruded strata were nearly or quite fused and softened the intruding rocks were considerably superfused, and were therefore not the immediately subjacent strata, but (as Lawson says) in all respects analogous to plutonics generally.

The granite intrusive in the greenstone schists back of Virginia is also porphyritic with red feldspar near the margin.

The Canadians made considerable concession to the point of view of Van Hise, Leith, Seaman and myself in regard to the limitation of the term Huronian and the division of the iron-bearing rocks and it seemed courteous to assent to their views in regard to the use of the term Laurentian, as this was a term of Canadian origin. Historically the Laurentian has been used with an idea of time to include everything thought to be earlier deposited than the Huronian rocks. This usage has been prevalent for a half century in this country and in Europe, and in the leading geologies of various tongues.[2]

Moreover, it seems to me clear that Logan's original and the Canadian usage had consistently recognized stratigraphic divisions in the Laurentian and an Upper and Lower Laurentian and included therein what I take to be probable sediments. But the true correlation of the Upper Laurentian or Hastings-Grenville series with the rocks of the Lake Superior region has yet to be made out. It may be that Logan's Upper Laurentian,

2 See for instance so late a book as Kemp's Ore Deposits, 1903, not to mention Credner, Lapparent, Geikie, Dana.

which contains so much limestone will prove to be equivalent to the Kona dolomite and rocks of the Lower Marquette series, here included in the Huronian. But should they prove to be coeval with the Keewatin series, it would then seem to me decidedly advisable to include the Keewatin-Hastings-Grenville all in the Upper Laurentian. The use of Huronian and Laurentian recommended in the general report of the committee will be nearly accordant with the use of those terms by Brooks and Pumpelly, my predecessors on the Survey. The fact is, as above shown, that Logan included in his original Huronian area, one small area of greenstone schist which is stratigraphically as old a formation as I know of. Moreover he and others had included large areas of similarly granite cut greenstone schists in the Huronian. This same group has also been called Keewatin by Lawson and it would have upset the Canadian ideas and mapping entirely to have counted them as Laurentian, while they can very well be called Keewatin until detailed study shows just what the typical Laurentian should include.

It is a euphonious term, geographic in origin, analogous to the Huronian and Cambrian, well fitted to take its place at the base of the geological column.

The term Archean has had an unfortunate history. Introduced by Dana possibly with some personal feeling to replace Azoic, it was avowedly to avoid the implication of lack of life and to include the earlier fossiliferous strata, and was always used by its eminent sponsor to include both the Huronian and Laurentian, as practically a synonym for pre-Cambrian.[1] It was, however, redefined by Van Hise acting for the U. S. Geological Survey, as pre-Cambrian non-clastic, and though he has since essentially modified his definition and included the Vermilion Iron Range and Keewatin, he would still exclude from it the Huronian and practically any fossiliferous character. It does not seem to me that clear thinking and mutual understanding will be promoted by adding a third sense to the two senses in which Archean has been already used. Moreover the term is not in origin and mode of formation analogous to Huronian. It will not be necessary for me often to use Archean in a sense different from that of the U. S. Geological Survey. I can simply avoid the term. As far as the usage of the Michigan Survey is concerned, the general connection of the rocks of the iron bearing ranges with Canadian Huronian has been recognized by Brooks, Winchell, Rominger and Wright, and as in Canada Brooks applied the term Laurentian to rocks supposed to be subjacent. But there has been much uncertainty as to the relations of the greenstone schists. Rominger included all the pre-Keweenawan rocks in the Huronian. In this I should have had to follow him, had the Canadians insisted that the Keewatin, Marinescan and all like greenstone schists be included in the Huronian, as some of them have been inclined to do.

I may say that, for reasons given above, I do not believe the rocks called Laurentian are a fused, immediately underlying formation and it seems to me that the system agreed upon can only be logically held as a stratigraphic one by those who believe in the subcrustal fusion of Lawson's theory. I do not. But as a temporary modus vivendi until we know more about the correlation of the Huronian and Laurentian it has advantages. The difficulty is that the original Huronian and original and typical Laurentian are in different areas and, as usually happens in all parts of the geological column, while the main points of the various systems are easily assigned there are difficulties in drawing

[1]See Geological Survey of Minnesota, Vol. VIII.

the exact line in all places, and there is a certain overlapping of concepts.

For the present the term Laurentian will be a convenient one under which to group certain large old batholites of plutonic rock.

GRAIN OF LOGAN SILLS, ETC.

I also had a chance to make observations on the grain of the basic intrusives in the iron bearing series, the trap dikes and the Logan sills and may sum up by saying that they generally appear to be in main features like the Keweenawan diabases which I have already described, the grain of the augite being indefinitely fine near the margin, increasing rapidly then more slowly and being almost or practically constant near the center and roughly proportional to the thickness of the intrusive. For instance: In a sill south of Loon lake near Port Arthur we have the following observations:

AUGITE at 2 feet (609 mm) is in granules 0.1 to 0.2 mm in diameter.

OLIVINE at 4 feet (1,218 mm) is 0.25 mm in diameter.

FELDSPAR at contact is sharply idiomorphic, up to 0.35 mm x 0.05 mm, with a second generation, a fine felt, 0.02 mm x .002 mm or smaller; at 609 mm there are sheaves of feldspar of variable size the two generations not so distinct 0.3 to 0.5 mm long; at 1,218 mm it is similar, on the whole distinctly coarser than at 609 mm, but the maximum not so very different, 0.4 to 0.5 mm.

MAGNETITE at contact is dust; at 609 mm is in triangular skeletal ochahedra about .2 mm; at 1,218 is coarser.

AUGITE at contact varies from one side of the large section to the other, is not over .02 mm; at 609 mm it is just beginning to be ophitic; at 1,218 it tends to cluster, .6 mm.

The rock appears to be as coarse at 4 feet as at the center of the sheet which was 15 or 20 feet thick. A section collected from near the top of Mount McKay, and from the crowning cap sheet shows a coarseness somewhat proportional, for according to Lawson it must be somewhere near 260 feet from the lower contact. The upper contact is eroded away but I suspect is not so far off, but unfortunately I could not locate either exactly. The lower was covered with debris. The augite patches of luster mottlings are plainly visible to the naked eye. I estimated them as 4 to 5 mm, but measurements on the section show that they are really about 6 mm in diameter. The thin section shows that when they began to grow there were labradorite feldspar laths, small, (.25 x .05 mm) but very sharp, which they enclose freely, while in their growth they pushed the granules of magnetite (.07 mm) and olivine before them. The feldspar continued to grow, and that enclosed near the margin of the ophitic patches is larger than that at the center. Finally in the interstices between the growing augite there was accumulated a probably hydrous solution of alkaline alumo-silicates and chlorides, etc., which reacting formed brown hornblende out of, or rather than, augite, biotite out of the iron oxides and magnetite, and a pegmatitic (granophyric) fringe of quartz and orthoclase (0.3 mm) upon the feldspar laths, and apatite, the most soluble residue presumably either remaining as a ("bergschweitz"), rock moisture in the interstices, as an aqueous solution chiefly perhaps of calcium magnesium and sodium chlorides, or passing entirely out of a given part of the rock to be collected in especial cavities or veins or driven forth. But such interstices are not visible, and may be supposed to amount to but a fraction of a per cent. as in the Light House point dike. The ophitic texture is thus not confined to effusive rocks entirely, though it is apparently not so conspicuous in the corresponding trap dikes and sills as in the effusives be-

cause the grain of the feldspar is usually much coarser in the former. It is however possible that the ophitic texture should be combined with the acid interstices which I have described as an acid intrusive texture. It is worth noting that these acid interstices resemble those ophitic "redrocks" which I have slightly touched on in connection with Mount Bohemia,[1] and have been described by Irving,[2] and the Minnesota geologists, Winchell and Grant.[3] While I can hardly go so far as to say with Winchell that the "gabbro and the redrock were simultaneously in a state of mobility," I have no doubt that they were consanguineous and that the redrock was intruded before the black rock, the gabbro, was cool. At Duluth I had a chance to examine once more in the quarry, four blocks west of the Spalding House, exposures of the Duluth gabbro and the red rock. The gabbro is full of large labradorite feldspar rhyocrystals, arranged in flow lines, up to 3 cm long. Near the bottom of the quarry is an intrusion of red rock. That it was injected soon after the gabbro is shown by the following facts: (1) the contact is closely welded; (2) it does not follow straight joints but runs irregularly; (3) near the center of the quarry it seems to saturate the gabbro, which appears redder and almost as though remelted; (4) the red rock has a decided grain at the margin even in 3 and 4 inch seams sometimes even coarser than at the center but in general is uniform in grain, showing that the country rock (the gabbro) was near the conditions of consolidation. Two possible hypotheses not altogether incompatible occur to me; first, that the acid interstices are the deposit of the last remnant of a hydrous magma, and secondly, since a hot rock cooling and crystallizing becomes denser, so much of this process as had taken place after it had hardened enough to fix the general form, which would produce a sugary granular texture unless new matter was sucked in, had done so and that this matter had crystallized in the form of these red rocks. N. H. Winchell (p. 98) speaks of "the penetration of the acid element into the basic along contacting"(contracting) "zones through the agency of mineralizers during the period of cooling." To this phenomenon he attributes the micropegmatite structure, and uralitic augite with chlorite and a reddened state of much of the feldspar, and is practically the second suggestion above.

If it can be shown that there is a certain eutectic ratio of silica to alkali, and that in the process of crystallization of a basic magma there is no tendency for the silica to increase above that ratio, which I have suggested may be 12:1, and that the red rock contained silica in excess of the ratio we could not consider it a remnant. The following analyses are from Mount Bohemia and No. 12 represents the red rock there, and in this case the alkalies are in excess of one-twelfth the silica. But similar analyses in some respects of a similar rock is given in volume V of the Minnesota reports, p. 89, and in that the silica is in excess.

[1] Volume VI, part 2; Annual report for 1903, p. 236.
[2] Copper bearing rocks of Lake Superior. p. 119.
[3] Vol. V, p. 59, 87 to 102, 978, 981.

MOUNT BOHEMIA ANALYSES.

April 16, 1904.

	No. 9.		No. 12.		No. 21.		No. 37.	
SiO_2	46.01	.767	62.28	1.036	44.91	.742	47.01	.783
Al_2O_3	16.95	.166	17.54	.172	18.01	.176	17.80	.175
TiO_2	2.48	.....	.98	.....	2.54	.....	2.19	.....
Fe_2O_3	5.14	.032	1.55	.010	4.50	.028	5.32	.033
FeO	9.83	.137	5.64	.078	7.64	.106	6.59	.092
CaO	6.71	.120	3.44	.061	7.49	.134	5.31	.095
MgO	6.20	.154	1.51	.038	7.67	.192	8.75	.219
K_2O	1.71	.018	2.97	.032	1.33	.014	1.58	.017
Na_2O	2.22	.035	4.26	.069	1.75	.028	2.00	.032
	97.25	1.429	100.57	1.496	95.84	1.420	96.55	1.446
Alkalies	.....	.053	.....	.101	.....	.052	.....	.049
Alkalies: SiO_2	.....	.69	.....	.97	.....	.70	.....	.625

L. KIRSCHBRAUM, Analyst.

Of these analyses No. 9 is the unaltered ophite, No. 12 is the red rock dike in the gabbro, while numbers 21 and 37 are from the ophite altered and recrystallized by the gabbro, showing hornblende zones around the augite. The figures on the right are molecular proportions.

GENERAL REMARKS ON THE IRON RANGES.

I have handled together for convenience the notes of my trip which refer to grain observations and those bearing on geological problems. We will now return to some other observations.

This trip gave me a chance also to see something of the vast supplies of ore on the Mesabi range, and the systematic way in which that range has been tested by holes each 300 feet apart.

In one tract of 200 acres there are said to be 120,000,000 tons of ore. It is fortunate for Michigan that the large owners there are also large owners on the Michigan ranges, and that there is a real economy of ore in mixing them. If it were left to cut-throat competition it would seem as though some of the Mesabi mines might, by wasting part of their ore and sacrificing much of their profits, put all other mines temporarily out of business. It cannot be doubted, however, that the present policy is the best in the long run.

Another feature that I noticed was that in points huge piles of waste stripping had to be rehandled again to make room for more extensive exploration. Down near Ishpeming, on Sec. 21, T 47, R 27, a great bluff of lean ore is being mined which when I was over it a few years ago was not considered worth mining. So on the Gogebic range the tendency now is to have foot wall shafts. The moral is that on planning work, dumps, shafts, etc., provision should be made for the future and the geology considered so as to make everything as permanent as may be, and generally speaking everything conveniently placed on the footwall side. It may also be worth while to stock pile for future use rather than stow underground rock too lean to work at present, down to say 35% iron.

Passing from the Marquette range we went to the Gogebic range where we found the section to be given in connection with our Black river work, which may be briefly summarized here:

Neo-Huronian. Greywackes and black slates—Tyler slate.

800. Iron bearing formation, cherty carbonates and slates ferruginous chert characteristic—Ironwood formation.

An apparently slight unconformity.

400. Quartzite and then red and green slate of the Palms formation, with a few narrow bands of basic tuffs. The base is a conglomerate with pebbles of dolomite, red jaspilite, granite, etc., on the granite—Palms formation.

Large unconformity from Ironwood to Bessemer.

Granite cut by various trap dikes altered to hornblende schists, and itself intruding, for instance near the Ironwood water tower, some very curious amphibolites—Mareniscan-Laurentian.

At Wakefield and Sunday lake there is a fault or possibly a very sharp fold by which this old greenstone schist series with veins of red granite or syenite is well exposed south of the lake, Sec. 16, T 47, R 45, while farther south is the iron series. But the iron series also appears on the north side of the lake close under and in close contact with the labradorite porphyrite which forms the base of the Keweenawan, and being devoid of cap hard ore jasper occurs.

There have been frequent rumors of late of an iron range south of Bessemer. None has been reported by any previous geologist, the country being supposed to be all Laurentian granite. Yet it is not impossible, and it might be worth while to continue the work of the Black river party of this summer by making a section from Bessemer to Wakefield southward.

Around Tower the greenstone schist series and especially the spheroidal greenstone were well developed and folded in or at times included either by shearing, or some process of filtration were bands of iron bearing jaspilite. But these things have been so fully set forth in the U. S. Geological Survey Monographs that I need not repeat them here. I will only make one comment. About six hundred paces south of Tower the greenstone schist series is cut by a porphyry which contains porphyritic oligoclase feldspar (of 2-4 mm.) Leith says it was as a field name called, and very fitly, the white-eye porphyry. It also occurs on the islands of Vermilion Lake and is there extremely hard to distinguish from a conglomerate or arkose composed of its debris. Now this feldspar matches exactly the oligoclase of a granite which is frequent in boulders of which these porphyries are but apophyses. Here again as usual the granite is intrusive in the oldest sedimentary series, the greenstone schist series, and I have never found it otherwise.

LAKE SUPERIOR GOLD MINING.

This excursion also gave me an opportunity to get a view of the Lake of the Woods, Rainy Lake and Seine River Gold Mining regions, and a glimpse of the mines. The general geological conditions are quite similar to those north of Ishpeming, the Ropes and Lake Superior Mines, a gold region where gold mining is now suspended. Mining is also at a low ebb in the Canada regions, only the Sultana being fully at work as a going and apparently well-paying mine. And yet the geological conditions appear to me to be not unfavorable for an established industry and worthy of careful investigation. In both regions the gold mines are located in a series of old, generally green, rocks, which underlie all the principal iron ranges but the Vermilion, and are apparently of about the same age as that. They are the greenstone

schist,—Keewatin,—Mareniscan. In both they occur in solid quartz veins, most of the rusty upper part having been removed. In both fine specimens of free gold occur, but the bulk of the ore is of low grade. In both the subsequent disturbance of these old rocks makes it hard to follow the chutes of ore.

These old rocks have in Minnesota and Canada been called the Keewatin. Around Rainy Lake City an abandoned stamp mill and a couple of log houses of the American mine are signs of the former boom, while two or three houses serve as rendezvous for fishermen and homesteaders, who take the tug for International Falls and Fort Francis here. On the north side of Shoal Lake, in the Seine river district, the rather extensive equipment of the Foley Mine is idle, and the village of Mine Center has every symptom of a burst boom, though I believe a little work is yet being done on claims not far off. The town is practically on an island, composed of conglomerate which fringes the north shore of the lake and overlaps unconformably a granite, the Bad Vermilion granite, which, together with a gabbro, is said to cut the Keewatin schists, and these two igneous rocks seem to have had something to do with the concentration of the gold. At the Lake of the Woods things are a little better. The country rock is still mainly the same greenstone schist series of crushed felsitic or basic rocks, making light-colored or green schists and pieced by a variety of igneous rocks. Mainly the explorations are in the basic rocks. I believe, though, at Gagneau's island there is an abandoned shaft 80 feet deep in an altered porphyry impregnated with pyrite.

The Sultana Mine is, however, working and appears prosperous. It is exploiting three or four veins, which lie near the contact of a diorite (which is accordingly quite porphyritic), with a volcanic agglomerate of the greenstone schist series. I understand that ore worth less than $7 to $8 a ton in gold can hardly be worked, and that much of the material raised from the Sultana will run from $14 to $15 a ton.

There is a custom stamp mill at Rat Portage, belonging to the Dominion Company, idle at the time of our visit, with Frue vanners, etc. This is only a few yards from the magnificent water power of Hebe Falls, and one would think could be very economically run by the same. As a whole, this district of greenstone schists along the international boundary has yielded perhaps a million and a half of dollars.

Now the gold region of Michigan is located in exactly similar conditions. Running west from Marquette and passing but a mile or two north of Ishpeming and Negaunee and bounded and overlain unconformably by the basement conglomerates of the regular iron bearing series of Negaunee and Ishpeming on the south and cut into by the granites on the north, and by a great many other igneous rocks, including some important masses of peridotite, is a series of green, largely volcanic, rocks, which correspond in composition and geological position to the Keewatin of Canada and the Lake of the Woods. They are known as the Kitchi and Mona Schists by the U. S. Geological Survey, the two terms indicating merely different degrees of alteration. In this series the gold product of Michigan, amounting to over half a million of dollars, has been found. The first discovery of gold in Michigan was made by State Geologist Douglass Houghton near the very region where gold has later been mined. In his biography by Bradish (p. 107), S. W. Hill is reported to have said:

"He was sent up with a party of men to where Negaunee now stands, and they pitched their tents a hundred rods northeast of the city, where the doctor was operating at the mouth of the Chocolate river. One day the doctor

visited their camp to see how they were progressing at that end of the survey. He arrived at the camp in the afternoon, and, after resting and refreshing himself, he took a pick and went out among the hills. Returning just before darkness set in, he said; 'Mr. Hill, are you aware we are in a gold region?' Mr. Hill replied that he was not. 'But,' said the doctor, 'we are;' and he took some specimens of rock from his haversack which were quite richly charged with gold. Mr. Hill asked the doctor if there was much of it. Dr. Houghton answered that he had not examined the ground very closely, and also said that he did not wish anything said about it just then, as they had already had some trouble with the men, and if these should become aware that they were in a gold region they might desert them to hunt it for themselves.

Unfortunately, that fall Dr. Houghton was capsized in a squall at Eagle river and drowned, and all his notes were lost with him. Mr. Hill says the doctor came from a northeast course—not from the northwest, as I have been previously informed—and that he could not have been over a mile or so away, which would be about on the range with the Ropes vein."

This would indicate that the gold was found in the Kitche and Mona Schists, northeast of Teal Lake, almost in the line of strike of the Ropes Mine.

The second chapter is due to Mr. Julius Ropes, of Ishpeming, who opened in 1881 the Ropes Gold and Silver Mining Company on the south half of the northwest quarter of Sec. 29, T. 48, R. 27. Here hornblendic rocks of the "greenstone schist" series, often known as diorite, are cut by peridotite,[1] and near the contact much talc and many gash veins of quartz are found. The gold is not confined to the veins, but impregnates the country rock more or less. The peridotite has been altered, yielding serpentine, talc, ferrodolomite, etc. The mine published full and instructive reports, which are embodied in the reports of the Commissioner of Mineral Statistics, but was hampered by a lack of capital and experience. The owners could not stand and did not declare heavy initial assessments, and it was never possible to open up far ahead or do as much selection as would probably have been wise. In 1886 from 6,959 tons of rock, with a tailing loss of 95 cents to $2.50 a ton averaging $1.90 a ton, the mine produced $43,499.93, or $6.20 per ton net, or $8.10 per ton gross. In 1888, however, 10,216 tons only yielded $34,930.66, while the loss in tailings is said to have been from 90 cents to $1.50 a ton. In 1891, 31,578 tons of rock yielded $65,240.67 net. The mine continued in operation until 1897, having been a considerable help to the city of Ishpeming in a season of dull times, and having produced $647,902.37 out of the $666,485.73 with which the Ishpeming field is credited. It had sunk about (15 levels) 850 feet and drifted 400 to 500 feet. Some very rich rock has, however, been found on other locations, and I am inclined to believe that the above total for the district does not include many thousands of dollars worth of gold carried off as specimens or stolen. Some of the other places which have been developed for gold are:

N. E. ¼ of N. W. ¼ Sec. 35, T. 48, R. 28, 275 feet west of the east line (Gold Lake and Superior). Specimens of this vein showed much free gold and assayed as high as $40,000 a ton.

The same vein runs east and west through the next property: N. W. ¼ of N. E. ¼ of Sec. 35, T. 48, R. 8, just east (Michigan Gold Mining Co.), and was wonderfully rich in gold near the surface, yielding $17,699.36 in a few months.

1 Wadsworth, 1891 report p. 143.

Sec. 36, T. 48, R. 28, has also yielded gold.

On Sec. 26, T. 48, R. 28, were the Peninsula and Grayling Companies.

On Sec. 21, T. 47, R. 27, was the B. & M. and the Fire Center Gold Mining Company was also near Dead River.

The Ropes Gold and Silver Mining Co. closed down in 1897, was bought at the auction sale of the receiver in 1900 by Corrigan, McKinney & Co. for about $12,000. They are said to have recovered from the amalgam plates with the gold contained alone more than the total purchase price. They removed the machinery and thus ended the second chapter in the history of gold mining in Michigan.

But I believe there are yet chapters to be written. Such competent and impartial judges as Newett and Lawton have expressed the opinion that the Ropes could be a paying mine. If it had had, as many of the copper mines have had, a half a million to start with, it might have paid dividends, worked continuously and opened up ahead. Our field has hardly been tested. We have seen that these rocks in which the gold occurs are extremely old. It is also probable that the disturbances which led to the concentration of the gold are very old, certainly before the last ice age, which has probably removed the most friable and easily crushed and richest part of many of the lodes, probably before the formation of the Lake Superior sandstones, and quite possibly earlier yet.

It is therefore not beyond the bounds of probability that the gold of the eroded part of the veins may have collected in rewashed glacial gravels, or at the base of the Lake Superior or Potsdam sandstone, as quarried in Carp River, or even in yet older conglomerates.

I am informed that up in the Lake of the Woods region and in other places in Canada the glacial gravels yield almost enough to pay to work, and it is liable to be so here.

Moreover, there are other areas of serpentine and large areas of greenstone schists which have hardly been touched. Gold has also been reported by Prof. C. D. Lawton from the Menominee river, south of Quinnesse and in connection with some of the iron ores.

BLACK RIVER WORK.

The resignation of Dr. F. E. Wright early in the spring to accept an urgent call of the U. S. Geological Survey was disconcerting, especially as it was desirable that he personally should finish some of the work which he had begun. This in fact in leaving he still hoped to do. It seemed to me that it would aid him in his task of unravelling the relatively complicated structure of the Porcupines to have a careful geological section of the copper bearing or Keweenawan rocks to the west, where they ran more regularly, as well as to the east. This would bring out the persistent horizons, and would also be worth doing in itself, and was suggested by Mr. L. L. Wright of the Board. I therefore made a trip to the Gogebic range early in the spring and with the aid of L. L. Wright of the Board examined the country north. The region is traversed by three rivers which starting from the granitic area (Laurentian) that occurs along the Wisconsin line flows across the Iron range and the copper bearing rocks. Of these the Montreal and Presque Isle had been the more carefully examined by Irving and others in his examinations for the Wisconsin survey and in his well known and admirable Monographs for the U. S. Geological Survey on the Copper Bearing Rocks of Lake Superior[1]

[1] Monograph V.

and the rocks of the Penokee Gogebic range. A hasty examination of the Montreal made it seem to me unlikely that new facts of so much interest would be gathered there as on the Black river. For his knowledge of this latter Mr. Irving depended on second hand information, not of trained geologists, and by some error, probably clerical, the work of the Chippewa Mining Co. on Sec. 32, T. 49 N. R. 46 E., was considered to be Sec. 22. The building by the State of the Black river road made the section by the river quite accessible, and my visit early in the spring and information of a former member of the Survey corps, County Surveyor George Rupp, indicated so many outcrops as to make it likely that a close geological survey would be rewarding. I accordingly instructed Mr. W. C. Gordon, whom Dr. Wright had recommended to succeed him, having been his assistant in 1903, to take charge of a field party to survey a strip of country four miles wide including the river from the lake to Bessemer.

His report and map I hoped to append to this report. I joined him during part of September and October. I have asked him to work my field notes with his. The results were even more rewarding than I expected.[1] For the first time in Michigan we found a westward extension into Michigan of the gabbros so widespread in Minnesota that were known to extend to Bad River, Wisconsin. I consider the evidence clear that it is a deep seated intrusive in the Lower Keweenawan. The feldspar tablets are often 2 to 3 decimeters in diameter, and the magnetite 5 to 8 mm across, so that its age is probably not earlier than middle Keweenawan. We found the upper intrusive contact well exposed. We found a felsitic horizon near North Bessemer which is, I think quite likely, that of Mt. Houghton and the Bohemia conglomerate No. 3. We found the great belt of ophites (lustre mottled melaphyres—see Plate XVII,) some quite coarse, which are the central part of the Keweenawan formation. The Chippewa Bluff felsite and associated beds appear to be near the horizon of the Ash bed series (Hancock West No. 17) and various beds above, the Nonesuch shale, outer conglomerate, lake shore trap, etc., were identified substantially as by Irving. Gordon was then able to obtain a fairly continuous section of the Keweenawan rocks from near Bessemer to the lake, and it appears, contrary to my expectation, that in this geological column of about 40,000 feet there is no important repetition by faulting to be proved. Irving's estimates of the thickness of the Keweenawan are thus confirmed. It does not necessarily follow, however, that all the 40,000 feet ever formed in a continuous vertical pile. Many evidences of unconformity within the series such as exist between the Keweenawan and underlying series also exist. In fact just here there are more evidences of unconformity between Upper and Lower Keweenawan than between Lower Keweenawan and Animikie, for the upper conglomerates have a much gentler dip and contain pebbles not only of jasper, but also of agatized amygdaloids and various other rocks of the Lower Keweenawan including various of the "red rocks" already described which were probably deep seated intrusives in the Lower Keweenawan and could have been yielded as pebbles to the upper beds only by considerable erosion of the lower. But though the south range does not appear due to be a mere repetition by faulting, but petrographically independent, there is faulting in plenty. Even in the spring it had been suggested to my mind that there was faulting. Conversation with Mr. J. R. Thompson, agent of the Newport mine, who thinks that most of the gaps in the copper

[1] Southeast part of Sec. 4, T. 47 N. R. 46 W.

range mark faults, when I visited the iron ranges with the international commission confirmed this impression, and careful study shows that he is probably quite right and gave undisputable evidence of extensive faulting across the formations. The Black river valley follows a fault most of the length as Gordon will describe more in detail, and within the four mile belt of his survey there are four or five similar faults. But while these faults in the Keweenawan have very considerable throws, back in the Iron range the amount of the throws are much less, though Mr. Thompson has found evidences of much faulting of similar nature. I made a little examination of the granite a little farther south, especially on Palms and Colby Hills and while there was evidence of jointing and veining and throws of a few millimeters parallel to the faults of the Keweenawan the amount was very minute. It is as though the whole country had been subject to the same type of stress, but the strain was possibly greater and the yielding thereto certainly greater as one goes progressively northward.

The most natural way in which one can easily conceive mechanically of a fault like that of the Bessemer fault with a horizontal throw Gordon computes of about a thousand feet and next to nothing at the granite but a mile or two away, is to suppose that there are also strike faults and that there has been slipping up and down on these faults but much greater in some places than in others. Of such strike faults Mr. Thompson has indeed found evidence, but curiously enough the throw in them appears almost strictly horizontal as though the gabbro in intruding from the west had tended to shove the strata westward ahead of it, while the granite acted as a resistent medium. But if it also crowded up or kept from collapse the block of strata west of the Bessemer fault it could produce the apparent displacement of the Bessemer fault. This faulting however displaces the Keweenawan dikes, the quartz diabases. It is worth noting that most of these latter dikes appear to have preceded the faulting. Many of them strike toward the Porcupine mountains as though that were an old focus of eruption or of stress.

The map prepared by Gordon is typical of the country west of the Presque Isle river and a section north through Ironwood should show essentially the belts and the same kind of faults. I see no reason why the Black river valley should not be a copper producing center, as well as that of the Ontonagon or Portage lake. We have the same variety of rocks, about as great topographic differences, and as much faulting.

The river has dead water for a half mile above its mouth. Dr. Wright in his report last year called attention to the fact that the water level of Lake Superior has been rising, drowning the mouths of the rivers.[1] Thus though a bar has formed across its mouth dredging would make a tolerable small harbor.[2] The river which is quite largely spring fed, shows a minimum horsepower of something like 125 H. P. for each ten feet of fall. It may be too far ahead to look to the time when there shall be a nice little port at the mouth of Black river, with a sawmill, lights and electric line to Bessemer and to mines back up the river, run by waterpower electrically transferred, which shall ship hemlock bark, lumber and copper concentrates, and receive supplies for copper and iron mines, but there is nothing geologically impossible in the vision. It is probably only a question of the willingness and ability of those who would profit by it to do the necessary development.

The dead water ends in falls. Thence above the river to the falls (on Sec. 32, T. 49 N, R. 46 W.) opposite Chippewa Bluffs, there is a rise of 380 feet

[1] Annual Report for 1903, p. 38; this report p. 104.
[2] The U. S. Engineers have reported on this project.

250 232 202 172

APPROXIMATE DISTANCE FROM MARGIN, IN FEET:

4 13 28 43

LUSTER-MOTTLING IN DRILL-CORES OF OPHITES.

and up to Sec. 30, T. 48 N., R. 46 W., as Gordon's map shows, there is over a hundred feet of additional fall available along the Black river road, mainly in rapids, with clay or rock foundations for water power.

Observations on the river[1] show that much of the way it cuts through

Date.	Gage readings.	
1904.	A. M.	P. M.
Sept. 26	8.6	9
Sept. 27	8.5	8.5
Sept. 28	8.5	8.5
Sept. 29	1.2	1.3
Sept. 30	1.5	1.5
Oct. 1	1.4	1.4 (1.38)
Oct. 2	1.3	1.3
Oct. 3	1.25	1.2
Oct. 4	1.15	1.1
Oct. 5	1.1	1.1
Oct. 6	1.15	1.15
Oct. 7	1.15	1.15
Oct. 8	1.15	1.2
Oct. 9	1.3	
Oct. 10	2.1	2.22
Oct. 11	2.3	
Oct. 17		(1.5) at 2.30
Oct. 24	[2.8]	
Oct. 29	[3.4]	
Oct. 30	[3.3]	

The gage readings were taken twice a day usually about 7 in the morning and 5 in the evening, but not with strict regularity. Observer generally J. G. Côté. Observations in parenthesis A. C. Lane, in brackets J. W. Vogtlin. Low water is not much below 8.5 I think.

sand into clay and its floodplain is lined by a swampy strip next the bluff fed by frequent springs. So that we should expect its runoff to be quite constant.

A section was also taken at the gage and 25 feet above as follows, beginning at a point opposite gage:

At gage.		25 feet above gage.
Feet.	Depth.	Depth.
32	0 waters edge	0
37	.40	.30
42	.65	.67
47	.66	1.01
52	.70	.98
57	1.00	1.11
62	1.20	.91
67	1.37	.92
72	1.44	.82
77	1.60	1.00
82	1.96	1.07
87	1.82	1.05
92	1.86	1.16
97	1.74	1.55
102	1.58	1.79
107	1.59	2.32
112	1.70	2.68
117	1.39	2.33
122	1.33	1.90
127	1.28	1.32
132	.89	.62
134	.85	bank.
135	.00	bank.

[1] A gage was set on Sec. 17, T. 48 N., R. 46 W., at the Narrows as shown. The gage was braced against an overhanging cedar in which a notch was cut and a nail driven at 4.5 of the gage, which is about the level of the flood plain.

Bank being cut vertically about 5 feet high into heavily wooded flood plain.

The cross-sections at this point seem to be in the one case 130.46 square feet and upstream 124.07 or say 125 square feet as an average for a gage height of .8. Observations of maximum velocity with floats check remarkably well in discharge curves, considering how rough they are.

At 0.86 on the gage the maximum velocity was 25 feet in 23 seconds.

At 1.38 on the gage the maximum velocity was 25 feet in 13 seconds.

At 2.2 on the gage the maximum velocity was 25 feet in 7 or 8 seconds.

These correspond to 1.1, 1.9 and 3.1 feet per second. For every foot increase in gage height I estimated the increased area by a formula [103+12 (a–.86)] (a–8.6) where *a* is the gage reading. The minimum discharge is not far from 110 cubic feet per second. The area above the gaging station I have not yet accurately computed; using Chas. Cumming's estimate in the Michigan Engineer for 1904, and subtracting 30 for the part of the basin below the station from 250 square miles gives 220 square miles or a low water runoff of .50 cubic feet per second per square mile. Comparing this with the records in Water Supply paper No. 83, pp. 246–262 of Upper Peninsula streams, we note that October is a month of low water, and that the runoff per square mile is comparable with the Dead River near the Hoist and the Carp.

DRILL CORE PRESERVATION.

I have also spent some time in studying the records of explorations and diamond drill holes by the Arcadian, Atlantic, St. Mary's, Wyandotte and Winona companies, but a report on the results of the same is not yet ready. The bulk of the material examined is, however, in that belt of ophites, which may be taken to be the center of the Keweenawan formation and is overlain by the ashbed group of melaphyre porphyrites and conglomerate 16 and underlain by conglomerate 3 and a group which contains many coarse Labradorite porphyrites.

I am invited to look over much more material. There are thousands of feet which would be sent us for examination if I had the place to bestow it. But we are crowded. In the meantime records of great interest to the geologist, and of practical value as well, which could be preserved to science for the mere cost of storage but have cost from $3.00 to $6.00 a foot to private parties who would generously put the information in the hands of the Survey after they have made their immediate use of it, lie mouldering in sheds, much exposed to fire and accidents which in displacing them will make their story forever illegible. It must be remembered that drill holes are rarely sunk but for one or two objects, for signs of copper, ore bodies, coal, salt, etc., and are scanned at the time with that object alone in view. The information they may incidentally afford in other directions can never be foreseen and is not obtained by those who examine them. This is not said in any spirit of criticism of the mining engineers for a similar remark might be made of my own work. One can never tell when some peculiarity that one supposed to be trifling may not prove of great importance. Even if I as well as others have examined the records it is well that they should be preserved. And whereas surface outcrops can generally be revisited, diamond drill cores can only be duplicated at a cost of thousands of dollars.

I would suggest therefore that a library of these stone records should be created, at some central point, preferably at the College of Mines, into which all the drill cores could be collected. It should be absolutely fireproof, of

concrete and steel. Wherever, and so long as desirable, the location of drill holes could be kept secret, being deposited in sealed tin boxes.

OPHITE.

There is one point, however, concerning which I have had inquiries, namely the term ophite, a term not original with me but which I first introduced into use in Lake Superior literature. Ophite is a shorter name for the kind of rock which Pumpelly called lustre-mottled melaphyre, and is used, whether the lustre betrays mottling or not and no matter what the coarseness of texture may be, for those flows which are composed very largely of feldspar tablets enclosed in crystalline patches of augite. The interstices of the augite have not the same hardness as the augite and are more easily decomposed. So that there is a lumpiness or a weathered surface, which I have illustrated in Pl. VII, Part 1, Vol. VI., as well as a mottling of luster, and on a ground surface like that of a pebble or drill core a mottled pattern is also brought out, which becomes coarser the coarser the augite grains are and the farther from the margin. This is shown in Pl. XVII. The rate at which this coarsening takes place is not absolutely uniform, depending on the composition of the flow, its temperature when it began to cool, and that of the rock over which it flowed and other factors. Yet an examination of the Isle Royale drill cores led me to the conclusion that for the majority of the Keweenawan ophites the following formula was true: $16\ (y \pm 1) = x + 20$ in which y represents the linear diameter through the larger patches in millimeters (305 mm = 1 foot) and x = the distance from the margin in feet.[1] The plus or minus term represents the range of error in getting the coarseness of the grain and all other sources of error. A still rougher formula is that the mottling is in proportion to 1 inch diameter for 400 feet distance.

I have reproduced as Pl. XVII for this report drill cores at the depths noted in St. Mary's Mineral Land Co. drill hole No. 5 a vertical hole. I take it that the dip of the strata is 59° and that the bottom of this ophite being at 257 feet in the drill hole they are really respectively 4, 13, 28 and 43 feet from it. According to this by the rough formula the diameter of the mottles should be .25, .82, 1.78, 2.73 mm respectively and by the closer formula 1.5 mm, 2.05 mm, 3 mm, and 3.93 mm respectively with a latitude of a millimeter. In a first quick estimate as I walked over the core boxes I put the grain of the sample at 245 feet at 1 mm, that at 228,2 mm, at 202,3 mm and 172,3 mm. I will leave it to the reader to say what the size of the mottling appears really to be.

I have had no thin sections made yet and it was upon measurements of these that the formula was based. I think it is plain, however, that with the naked eye one can tell somewhat nearly what the grain is and whether it is becoming coarser or finer and have some idea how far off the next amygdaloid is by comparing with the cores shown in the plate.

WELLS AND BORINGS.

Our notes on wells may be divided into two classes. First we have those which are of comparatively moderate depth and put down for water, like those at Battle Creek, Holly, etc.

All our notes on this subject are going into the hands of Mr. Frank Lever-

[1] This is a correction of the misprinted formula on p. 129 of the Isle Royale report, which as is obvious does not agree with the figure opposite.

ett, who is preparing a water supply paper for the U. S. Geological Survey on this subject to replace my papers 30 and 31 which are out of print.

Mr. Leverett and I have been conducting a series of observations on the temperatures of relatively shallow wells, 10 to 200 feet deep, with the object of finding out what indication the temperature is of the depth of the source and how it is affected at different times.

In regard to deep wells, we shall hope to take this matter up for more careful treatment in the report for next year. The following letter from Mr. Ellinger is, however, of current interest[1] and we will also include a few wells of some especial interest.

LETTER REGARDING OIL NEAR ALLEGAN.

FREMONT STATION, SEATTLE, WASH., March 20, 1904.

Alfred C. Lane, Lansing, Michigan.

Dear Sir—Your letter of the 7th just reached me. You will see from the above that I am far away from home. Now in regard to the borings in Allegan, will say that four more wells were drilled since I sent you samples.

I forgot whether I reported to you or not that we shot No. 2 well. Now if my memory serves me right I think not, so I will give you a history of it. The well produced some oil; say two to three barrels per day of 24 hours. Not being satisfied with this after pumping it for several weeks, I suggested having it shot and ordered 20 quarts of glycerine; realizing that would hardly be enough to clean itself and also afraid to use more, on account of the shallowness of the sand. If we had used two shells instead of one it would have shot into the blue shale and filled up our well. So we thought we would try one shell of twenty quarts. The result was, after the shot went off it failed to clean itself. By this I mean there was not power enough behind to throw up all the rubbish onto the surface and leave a clean hole. As soon as the report was over I run the sand pump down and found it was bridged over, so I run the measuring line down to find out where the bridge was; we located it in the blue shale.[2] I then ordered the drill sent down to clean it out (which was a little dangerous of getting fast on account of the caving in). Being very careful we broke the bridge and got an opening to the oil. We then cleaned it all out with the sand pump and brought up oil. We then put down the tubing and commenced to pump oil and salt water—more water than oil. After pumping several days I noticed gas escaping at the mouth of the well; so adjusted a 1" pipe to the side of the drive pipe and piped the gas to the fire box under the boiler, which almost made fuel enough to pump the well. We pumped the well steady for over two weeks day and night into a 100 barrel tank and measured the amount of oil it would produce, which was a little over three barrels per day of 24 hours. We then shut down about four hours, then the salt water accumulated so fast it shut off our gas. We again pumped the well for four weeks, but could not notice any increase, so we shut down again for a few days. After pumping off the head and getting below the gas vein I detached the 1" pipe from fire box and turned it up perpendicular and lit the gas to demonstrate to the public that we had gas as well as oil; it burned a blaze about five feet high and would continue so as long as we pumped the well and kept salt water down. We believe we made a good test of this well but found that there was not oil enough in it

[1] Grand Rapids Herald, 1, 30, 1903. M. Egan of Washington, Pa., was hoping to try again.
[2] See Plate IV of Vol. V. Lane.

in paying quantities so we abandoned it. In less than four weeks after oil came within two feet of the mouth of the well and never lowered. A year ago a firm from Ohio took all the casing and drive pipe out of the wells in town.

Our No. 3 well on the hill was similar to No. 2 as far as shales and limestone was concerned. We struck sand at 1,328 feet and drilled down to 1,411 feet—no show of gas or oil; but the sand when first struck was the best showing for oil I have found in Michigan. I mailed a sample of it to experts in Ohio who pronounced it fine oil sand. A party from Pennsylvania drilled a well about one mile due west of our No. 3. I watched this well every day while drilling and was there when oil was struck which amounted to about a 10 quart pail full. Oil was struck after 1 o'clock at night so drilling was shut down until morning. I was there at 6 o'clock when they commenced to steam up and let the sand pump down which brought up nothing but salt water. This well was at once abandoned. Two years later the Bangor, Mich., people hired me to oversee the boring of a deep well. The contract was let for a deep well 2,500 feet unless gas or oil was found sooner in paying quantities. At 1,180 I think (I have mislaid the record of it) salt water was struck which amounted to several barrels a day. This was a very difficult well to drill owing to the hardness of the rock at that depth. The contractor threw up the job and after weeks of waiting another party took the contract to finish the hole. The deeper he went the harder the rock and the more salt water which soon filled up the hole to about 600 feet, and at about 1,205 feet he pulled out his tools and threw up the job. I saved samples of this well and ordered them sent to the State Geologist by a party in Bangor.[1] I was called away and could not attend to it.

A little over a year ago two more wells were drilled in Allegan by Pennsylvania people; a little oil was found but not paying. Over five thousand acres were leased. The party died and the leases were returned. Last summer another party wanted to lease and drill a test well but people around Allegan would not lease so he went back East.

This I think ends the Allegan oil business. I became discouraged and moved to this state. I truly believe oil will never be found in paying quantities around Allegan—you might find small pockets but that is all.

Now Mr. Lane if there is anything more you wish to know and I can answer it will be pleased to do so. I surely would be pleased to receive your annual report for 1901 if you think I am entitled to it. Hoping I have answered all satisfactory, I am,

Yours respectfully,

(Signed) J. G. ELLINGER.

Personally I believe the time is near at hand when wells that run two barrels a day will not be sneezed at. The formation struck in these wells is the Dundee or Corniferous of Canada and Port Huron, where none of the wells are great producers but they tend to be durable.

UPPER PENINSULA.

In regard to the Upper Peninsula, and in connection with Prof. Russell's paper the record from Manistique in the annual report for 1903 (p. 140) should be consulted. Another well just outside the state in Marinette is of interest as confirming my theory that that part of the state is underlain by

[1] These have never been received. I have vainly tried to locate them. Information thankfully received. Lane.

the Huronian iron bearing rocks at no great depth. This well is only 8 feet from the one reported on in 1903 (p. 130) and struck it about 860 ft. so that hereafter the water discharged through the old hole. On the old tools the new deflected and went down to 978 feet. Mr. H. B. Simcox who kept a careful set of samples is inclined to believe that the oil comes from vugs in the limestone as at Rapid River, rather than works up from below. He says that at 435 feet the two wells were in the same bed and it appears from a geological map that they started in nearly equivalent horizons.

In consequence of comparisons of samples it seems possible that there is a hundred feet error in the facts given in 1903 (p. 123) as regards Oakwood.

MARINETTE WELL.[1]

Surface sand and gravel	69	69
Galena dolomite	121	190
Trenton dolomites, brown and blue shaly (at 260 to 275 sandy)	135	325
St. Peters sandstone	75	400
Calciferous (Lower Magnesian)	180	580
Potsdam	215	795
PreCambrian.		
Cherty or jaspilitic arkose quartzite	183	978

I think it probable that the bulk of Menominee county is underlain by the iron bearing formation at no great depth. I do not think it wise for wells to go far[2] into this formation until the surface distribution has been better made out by wells less than 1,000 feet deep which will probably encounter often good artesian water, softer in the Potsdam or Lake Superior sandstone than above, and *may* encounter in the dolomites pockets of gas or oil of small commercial value, especially if an oil bearing stratum should be found covered by a heavy coat of clay till. However, the Rapid River well is said to be booked for 2,000 feet and will perhaps show that I am wrong.[3] I should think, however, that better chances for oil or gas would be in going to the area covered by Lorraine, Utica or Niagara, and trying to see if the Galena-Trenton did not have oil somewhere when covered by the Utica black shales. Interesting in this connection are reports[4] of oil in Manitoulin Island, Canada, at a depth of about 400 feet.

LOWER PENINSULA.

Wells at Muskegon, White Pigeon, Bridgman, Milan and around Fowlerville have received brief treatment in last year's report. A well is now going down at Ypsilanti which expects to go further than any previous ones. I take it that it went through the Traverse between 291 and 320 feet. We have taken some temperature observations, and a fuller record we hope to make when complete.

We are investigating the Swan well 2,370 feet deep at Grosse Isle. This was supposed to be to blame for the drying up of certain wells near Carleton but from the known strike and dip of the strata I thought it unlikely and

[1] Letter W. C. Alden, Nov. 6, 1904, agrees with these observations.
[2] Menominee 4-15-1904. Gladstone Delta, 7-23-1904.
[3] Gladstone Delta, 7-23-1904.
[4] Detroit Journal, Sept. 24, 1904. Toronto Globe Sept. 24, 1904, as [illegible] Rosseau near east end.

Mr. M. L. Fuller of the U. S. Geological Survey to whom I referred the question and who has presented the report previously given agrees with me.[1]

It seems to me that more attention should be paid to minor flows of gas and oil, which may be worth saving even if they cannot make millionaires—such flows I mean as those struck: at Adrian, at Bailey Park at 136 feet, probably from a gravel bed at the base of the drift,[2] at Bear Lake, 419 feet deep, flowing both gas and water.[3]

I have also had occasion at request to prepare sections of what would probably be encountered at various depths, at various points.[4] I do not pretend to know just how much gas, oil or water is going to occur at various depths, but I can estimate at what depths they are most liable to occur, and this is often of use to drillers in planning their casings, the diameter of their holes, etc.[5]

Sometimes I am nearer right than other times. Mr. J. H. Killmaster was kind enough to write regarding the Harrisville well that[6] "your estimate of the depths of the rock was practically correct and that we encountered the formations that you said we would."

The record of the well as actually developed was:[6]

HARRISVILLE, Alcona County Court House, 640 A. T.

Post glacial and outwash.		
Yellow loamy soil	12½	12½
Quicksand	14	26½
Red clay	6½	33
Gravel	6	39
Glacial.		
Wisconsin. Last till *sheet* (sand of mixed character, boulders, etc.)	60	99
Interglacial.		
(Quicksand, solidified to a blue hard pan at base.)		
Sand, signs of oil	30	129
Earlier till sheet.		
Red hard pan	59	188
(Weathered till sheet.)		
Red clay	4	192
Blue hard pan and pebbles	38	230
Berea Grit.		
White *fine* grained sandstone	30	260
Antrim.		
Light gray shale Bedford or weathered black shale	149	409
Brown and black shale	97	506

The Manistee (East Lake) well, put down by T. Percy in about five months, finished August 1, 1904, striking 20 feet of salt at 2,025 feet.[7] It reached

[1] Detroit Free Press, Aug. 31, 1904.
[2] Bay City Tribune, Aug. 26, 1904.
[3] Jackson Press, Oct. 26, 1904.
[4] Harrisville: Alcona Review, July 28, 1904. Sherwood: Coldwater Reporter, April 30, 1904.
[5] July 21, 1904.
[6] As compiled by me from the samples, with assistance of F. Leverett and W. F. Cooper. See also Alcona Review, July 28, 1904.
[7] Traverse City Eagle, Aug. 3, 1904. Ludington Chronicle, Aug. 31, 1904. Michigan Investor, March 26, 1904. Detroit News, Aug. 1, 1904.

1,300 feet about March 26th and the shaft was then almost full of water. It was mainly limestone below. The salt was as deep as in the Peters well showing no upward bend, and no oil or gas worth mentioning was struck.

In closing this report, my last to the present Board, may I express my pleasure at the pleasant personal relations which have subsisted, and my hope and belief that the fact that its president and secretary are about to retire will not mean the severance of the same, nor imply a lessening of their interest in the development of our knowledge of the natural history of a state whose almost matchless variety of resources makes her geology an inexhaustible field of research.

Very respectfully,

(Signed) ALFRED C. LANE.

December 1, 1904.

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